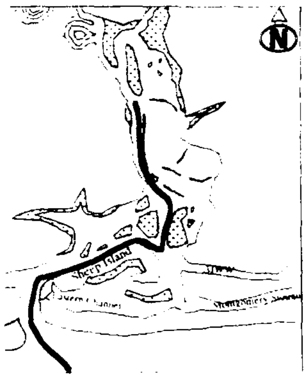
TECHNICAL REPORT HL-92-2

LOCKWOODS FOLLY NUMERICAL CIRCULATION STUDY



by

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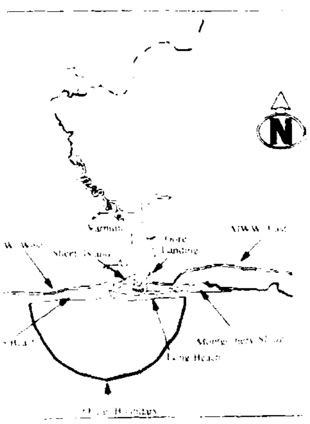

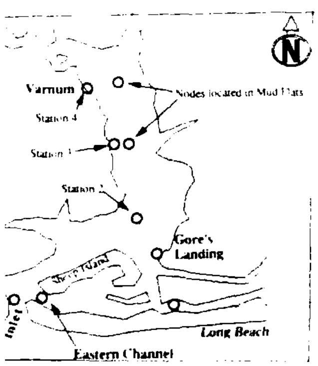

February 1992

Final Report

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13. ABSTRACT *(Maximum 200 words)*

The region around Lockwoods Folly River and Inlet, North Carolina, has experienced increased development in the past 50 years. In addition, the inlet has been changed by the addition of the Atlantic Intracoastal Waterway (AIWW). There have been concerns that the circulation is not sufficient to maintain good water quality. These concerns led the US Army Corps of Engineers to conduct an investigation to determine the effect of the AIWW on overall circulation patterns. The technical approach for this investigation was built upon the TABS-MD finite element modeling system. The two-dimensional model for hydrodynamics was first validated to limited prototype data, then used in conjunction with the transport model to predict the changes in tracer levels between the base condition and three plan conditions.

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Lockwoods Folly Inlet
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PREFACE

The work reported herein was performed in the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES) as a part of an investigation into the circulation of Lockwoods Folly River and Inlet for the US Army Engineer District, Wilmington (SAS). This report presents the results of the two-dimensional numerical modeling work.

The investigation was conducted from 1991 to 1992 under the direction of the following personnel: Messrs. F. A. Herrmann, Jr., Chief of the Hydraulics Laboratory; R. A. Sager, Assistant Chief of the Hydraulics Laboratory; W. H. McAnally, Chief of the Estuaries Division, Hydraulics Laboratory; D. R. Richards, Chief of the Estuarine Simulation Branch, Estuaries Division; and Project Manager R. A. Evans, Jr., Estuarine Simulation Branch.

The following individuals contributed to the preparation of this report: Mr. Robert A. Evans, Jr., author, and Messrs. Richards, McAnally, and R. C. Berger, who assisted in analysis of the results. Mr. T. C. Pratt, Estuarine Processes Branch, Estuaries Division, led the field data collection.

Mr. M. J. Wutkowski, SAS, served as the District's project coordinator.

Dr. Robert W. Whalin was Director of WES. COL Leonard G. Hassell, EN, was Commander and Deputy Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609344	kilometres
pounds (force)-second per square foot	47.88026	pascals-second

LOCKWOODS FOLLY NUMERICAL CIRCULATION STUDY

PART I: INTRODUCTION

Objective

1. The purpose of this circulation sensitivity study is to determine the impact of the Atlantic Intracoastal Waterway (AIWW) on tidal flushing in the Lockwoods Folly Inlet area and to determine the effect of possible remedial measures. The study scope of work did not include a detailed or a verification effort due to funding restrictions. However, short of collecting a verification set, limited field measurements were made to give insight into the behavior of the flows.

Background

2. Lockwoods Folly River is a tidal river that is located on the southern coast of North Carolina (Figure 1). It is typical of many smaller rivers that empty into the Atlantic Ocean in the coastal areas of the southeastern United States. Freshwater inflow rates are very low. Navigable depths are generally less than 15 ft,* and there are extensive tidal marshes which are inundated under high tides. Dredging in the river itself is infrequent, but the AIWW, which crosses the river near its entrance to the Atlantic Ocean, requires periodic dredging. The inlet to Lockwoods Folly River and the interior channel have experienced both natural and manmade geometric changes over the years.**,†

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* A table of factors for converting non-SI units of measurement to SI (metric) units is found on page 3.

** Langfelder, J., *et al.* 1974. "A Historical Review of Some of North Carolina's Coastal Inlets," Report No. 74-1, Center for Marine and Coastal Studies, University of North Carolina, Raleigh, NC.

† J. L. Machemehl et al. 1977 (June). "Flow Dynamics and Sediment Movement in Lockwoods Folly Inlet, North Carolina," Sea Grant College Publication UNC-SG-77-11, Center for Marine and Coastal Studies, University of North Carolina, Raleigh, NC.

3. Water quality has recently become a source of concern in the area. Residential development along the river has increased and there is concern that tidal circulation in the river is insufficient for maintaining good water quality. There is a need to determine the impacts of the AIWW and Lockwoods Folly River channels on tidal flushing. The development of a tidal hydrodynamic and constituent transport model can determine baseline circulation in the area and evaluate the effect of alternative geometries on tidal flushing.

Approach

4. Since Lockwoods Folly River, in the area of interest, is vertically mixed, the most appropriate modeling tool is a vertically averaged two-dimensional (2-D) numerical model. It is able to define accurately flow circulations between the Atlantic Ocean, the AIWW, and Lockwoods Folly River. A 2-D finite-element model is ideal for this task since the area has a highly irregular shape with significant mud flats and marsh areas (Figure 2). The Corps' TABS-MD modeling system was used to define the tidal hydrodynamics of the system and to conduct the transport studies. For a detailed description of TABS-MD, see Thomas and McAnally.*

5. The specific approach consisted of modeling the entire system from offshore in the Atlantic Ocean to the upper extremes of the Lockwoods Folly River. A significant portion of the AIWW, both east and west of the inlet, was also included (Figure 3). Prominent features such as secondary channels and adjacent marshes were also modeled. The TABS-MD hydrodynamic model, RMA-2 was used to simulate tidal flows over both 26-hour and 22-day periods. The 26-hour simulation was used in validation while the 22-day simulation was used for plan comparison. Transport studies were done using RMA-4. RMA-4 is able to track loads from multiple release points.

6. Four geometries were tested. Boundary conditions were defined at the ocean with either an actual tide record (for validation) or a harmonic tide (sensitivity tests). The following geometries were tested:

  a. Base (existing) condition.

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* W. A. Thomas and W. H. McAnally, Jr. 1985 (July). "Users's Manual for the Generalized Computer Program System: Open-Channel Flow and Sedimentation, TABS-2," Instruction Report HL-85-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

b. Plan 1 - same as Base, but with a small (8 x 100 ft) channel around Sheep Island and through Eastern Channel.

c. Plan 2 - AIWW removed and channel depths set to 1934 dimensions. (The depths in the river from the AIWW to Varnum in 1934 were approximately 6-8 ft, as opposed to 11-15 ft at present; in the channel north of Sheep Island 10-12 ft, as opposed to 16 ft.)

d. Plan 3 - Same as Base, but AIWW removed.

PART II: HYDRODYNAMIC MODEL VALIDATION

Survey

7. A limited set of field data was collected by WES personnel 10-12 June 1991. Water surface elevation and water velocity data were collected (Figure 4). Tide data were collected in the Atlantic Ocean at the Long Beach Fishing Pier and in the Lockwoods Folly River at Varnum, NC (near channel marker 12). Tide data were collected using Environmental Devices Corporation (ENDECO) model 1029 water level recorders. The ENDECO model 1029 recorders contain a strain gage type pressure transducer located in a subsurface case which is used to record absolute pressure of the column of water above the case. The pressure is measured for 49 seconds of each minute of the recording interval with a frequency of 5-55 kHz to filter out surface waves. The accuracy is ±0.1 percent of full scale (0-50 ft). The sampling time interval was set to 5 minutes. The time histories of the water levels are shown in Figure 5. Note that the gage mounted on the Long Beach Fishing Pier was broken from its mounting approximately 54 hours after installation. The data collected during the survey period were not affected by this. The water surface data collected at Long Beach was filtered by removing any components with periods less than 2 hours (Figure 6). The filtered data were then used as the ocean boundary condition to validate the model. (Note that validation implies that the model is sufficient to reach the stated objectives of this study. In order to have a more accurate, verified model, a more comprehensive field data set would need to be collected.)

8. Velocities were measured hourly at four locations. Station 1 was in the inlet, Stations 2, 3, and 4 were in the river channels at channel markers 4, 8, and 12, respectively (Figure 4). The data were collected using an InterOceans Model S-4 electromagnetic current meter. The S-4 is a 10-in.-diam sphere that measures the water velocity using an electromagnetic field to sense electric current induced by the movement of water through the field. The accuracy of the S-4 current meter is ±2 percent of the reading. Each reading represents a 20-sec average. In order to determine the amount of variability in the velocities, four successive measurements were taken at each station, two readings near the surface (2 ft below) and two near the bottom (2 ft above). Appendix A lists these data.

9. A 26-hour simulation was made with RMA-2. The surface elevations measured at Varnum, NC and the values predicted by RMA-2 are shown in Figure 7. While the phasing is good, the model does not show the range that the field data do. This is due to the wind, which was blowing predominantly from the south and southwest during the survey and which was not included in the model. Prototype versus model predictions are shown in Figures 8-11. The agreement between model test and data is sufficient for the purposes of this study.

Hydrodynamics of the Plan Tests

10. The simulations for the plan tests covered a period of 22 days. This ensured that there was a sufficient spin-up time before the 14.44 day, spring-neap cycle used in the transport studies. The ocean tide boundary was generated by harmonic reconstruction, with model time 0 corresponding to 0:00 EST on 5 June 1991 (high tide). Viscosity was based on cell size and Peclet number (cell Reynolds number, $P = UL/\epsilon$, U = average velocity, L = average length, ϵ = eddy viscosity). The viscosity values were computed based on an average length dimension of each computational mesh element in a specific type, a cell Peclet number of 20, and the highest expected velocity. Since all the elements of a specific type were generally not oriented in the same direction, the average greatest length of each material type was used as a guide for selecting the viscosity used in the hydrodynamic model. Roughness (Manning's n) was based on water depth and geographic location (marshes were set rougher than river channels). The viscosity and Manning's n values used for each type are listed in Table 1.

Table 1

Viscosity and Manning's n

Type	ϵ, Viscosity lb-sec/ft^2	Manning's n	Type of Area
1	25.00	0.016	River channels
2	60.00	0.020	$0.5 < Z < 2.0$*
3	80.00	0.035	$-0.5 < Z < 0.5$*
4	80.00	0.070	Marsh
5	150.00	0.160	Upland marsh
6	100.00	0.025	Open ocean
7	135.00	0.060	Sandbars
8	50.00	0.020	Upper river
9	40.00	0.016	Inlet to approx. sta 2
10	95.00	0.025	AIWW
11	20.00	0.160	Uplands and creeks
12	25.00	0.016	Midriver channels

* Z is water depth, positive values down.

PART III: TRANSPORT RESULTS

Analysis of the Three Source Simulation

11. The Base condition was used to show how tracers placed in three separate areas spread to other areas of the system. Three different tracers were modeled. Each had identical properties (decay rate = 0). Only one tracer was introduced into each of the load points. These load points were specified to be at Varnum, in the Eastern AIWW, and in Montgomery Slough (Figure 12). Each was introduced at a rate of 10,000#/1000 ml (the # symbol stands for "counts"; the tracer units are in "counts per 1000 ml") per second for the first 6 hours of the simulation. After the initial 6 hours, no more tracers were introduced into the system. The concentration levels versus time for the three tracers at 9 locations are shown in Figures 13-21. The locations are shown on Figure 4.

Inlet and river channel

12. The tracers from Varnum and the AIWW reached the inlet at nearly equal levels. The tracer level from the Montgomery Slough source was much less than from the other two release points. At Station 2, the dominant tracer was from Varnum, with the other two much less significant for the first 4.5 days of the simulation. At Station 3, again the dominant tracer was from Varnum, with its strength falling to the levels of the other two after 7 days. At Station 4 (which is where the Varnum tracer was released), the Varnum tracer level remained above the other two for the entire 14-day simulation.

Eastern Channel and Montgomery Slough

13. Although the dominant tracers in the inlet during the first day were the ones released at Varnum and in the AIWW, the most significant tracer in the Eastern Channel was from Montgomery Slough. Moreover, the levels of the Varnum and AIWW tracers in the Eastern Channel were nearly identical.

Other locations

14. The tracer levels at Gore's Landing (Howell's Point) were nearly equally divided between the three sources. However, in the two locations upriver in the mud flats, the predominant tracer was from the Varnum release.

Flushing Simulations

15. Determination of flushing differences between the Base and plan

geometries was done using three methods. The first method compares plots of 50 percent tracer concentration reduction times for each of the four geometries. The second compares the absolute differences of concentration values of the three plan geometries and the Base for the high and low tide of the last tidal cycle simulated. And the third compares the cumulative flushing rate of the area between Sheep Island and Varnum. Each simulation started with a tracer concentration of 100#/1000 ml everywhere. There was no freshwater inflow and the only place for the tracer to exit the system was the ocean boundary. When the flow was out of the system (i.e., the tide was falling), the tracers went straight out the ocean boundary. When the flow was into the system (tide rising) the tracer level at the boundary was defined to be 0.65 (an arbitrary but reasonable value) of the value at the boundary for the previous time step.

Reduction Times

16. Figures 22-25 show the 50 percent reduction time (days) for the Base, Plan 1, Plan 2, and Plan 3 geometries, respectively. While there are noticeable differences between the Base and Plan 1 (predominantly in the lower part of the system), the most significant difference is shown between the Base and Plans 2 and 3.

Base versus Plan 1

17. Plan 1 is the same as the Base except for an improved channel around the southern side of Sheep Island through Eastern Channel. This channel does not noticeably increase or decrease residence time in the upper part of the system and only seems to redistribute tracers in the lower part.

Base versus Plan 2

18. Plan 2 geometry is the most significantly different geometry, and therefore, it would be expected to show significant difference. The geometry differences between Plan 2 and the Base are that the AIWW has been removed and depths in the inlet and river channels have been reduced from 1991 depths to 1934 depths. The effect is that there was a slight decrease in tracer residence times along the eastern shore of Lockwoods Folly River, upstream of Gore's Landing.

Base versus Plan 3

19. Plan 3 was run to determine if the absence of the AIWW or the

historically shallower channels was the reason for the slight flushing improvements seen in Plan 2. Plan 3 is identical to the Base with the only difference being that the AIWW was removed, as in Plan 2. Residence time was lowest for this plan.

Plan versus Base Differences

20. Figures 26-28 show snapshots of the concentration values for the Base condition at high tide, low tide, and high tide, at the end of the simulation run. These illustrate that the tracers are pushed upriver during flood and are drawn downriver during ebb. Figures 29-37 show the difference between the three plans and the Base condition at these same time steps. Negative differences indicate that the plan has lower concentration levels than the Base. Note that the speckled appearance in the marsh areas are due to the wetting and drying algorithms and generally represent fluctuations of ±1#/1000 ml.

Plan 1 - Base

21. Figures 29, 30, and 31 show the difference between Plan 1 and the Base. At the high tides (Figures 29 and 31), the absolute differences do not exceed 3#/1000 ml with the average difference throughout the area shown equal to -0.1#/1000 ml. At low tide (Figure 30), the absolute differences are also less than 3#/1000 ml with the average equal to -0.5#/1000 ml. The negative average values indicate that Plan 1 flushes better than the Base, but the small magnitude of this average indicates that the difference between the Base and Plan 1 is insignificant.

Plan 2 - Base

22. Figures 32, 33, and 34 show the difference between Plan 2 and the Base. At the high tides (Figures 32 and 34), the absolute differences rarely exceed 5#/1000 ml with the average difference throughout the area shown equal to -0.8#/1000 ml. At low tide (Figure 33), the absolute differences exceed 5#/1000 ml in the channel north of and around Sheep Island. The average difference is -3.7#/1000 ml. Whether this negative value is due to the removal of the AIWW or to the shallower channel depths of Plan 2 is not clear from these results.

Plan 3 - Base

23. Figures 35, 36, and 37 show the difference between Plan 3 and the

Base. At the high tides (Figures 35 and 37), the absolute differences exceed 5#/1000 ml throughout much of the area. The average difference is approximately -5.7#/1000 ml. At the low tide (Figure 36), the absolute differences also exceed 5#/1000 ml throughout the area, with an average difference of -7.2#/1000 ml. The differences between Plan 3 and the Base are much greater than the differences between Plans 1 and 2 and the Base. Figures 38-40 show the actual concentration levels for Plan 3 at the three selected time steps. Comparison with the corresponding time steps for the Base (Figures 26-28) illustrates the considerable differences between Plan 3 and the Base.

Cumulative Flushing Rates

24. The cumulative flushing rate was determined by summing all the areas which had decreased below 50 percent of the initial value by a certain time. This is illustrated in Figure 41. This represents the area from north of Sheep Island to Varnum (approximately 37 million sq ft). This shows that for the first 7 days of the simulation, the decrease in tracer concentration is the same. At the seventh day, the curves start to diverge, indicating an increased flushing rate for some geometries. Figure 41 shows that the plans' tracer concentrations decrease faster than the Base. In particular, Plans 2 and 3 decrease faster than Plan 1 and the Base. The time required for half of the area to be reduced to 50 percent of the initial value ranges from 9 (Plan 3) to 10 (Base) days. At day 13, over 96 percent of the area is flushed to half of the initial concentration for all geometries.

25. The shapes of the curves are basically the same. The curves diverge between days 7 and 10, but are basically parallel from day 10 to 11, when they begin to converge. This indicates that, after rapid flushing begins between days 7 and 10, all the plans flush at approximately the same rate. The delay in the Base and Plan 1 conditions is caused by either an increased flushing due to the absence of the AIWW or by the added mass of tracer initially in the AIWW. Figure 42 shows the tide predicted near Varnum for the Base condition. Also shown is the difference between Plan 3 and Base tides at the same location. High and low tide levels are the same for Base and Plan 3. Figure 43 shows the difference in water surface elevations for the area at high tide on the 15th simulation day. These indicate no change in the tidal prism (Surface area times tide range). This indicates that the time at which

rapid flushing begins is determined by the total tracer mass initially in the system. Both the Base and Plan 1 include the AIWW, therefore, they initially have significantly more tracer mass. The extra day required before the Base and Plan 1 begin rapid flushing is the time needed to reach an equilibrium with the tracer mass from the AIWW.

PART IV: CONCLUSIONS

26. As stated in paragraph 1, the primary objective of this study was to determine the effects of the federally maintained Atlantic Intracoastal Waterway (AIWW) on the flushing of the Lockwoods River. Two plan geometries were studied which had the AIWW removed, Plan 2 and Plan 3. Plan 2 also had the depths in the channels restored to 1934 values. Channel depths in Plan 3 are the same as the present (Base) conditions. One plan geometry, Plan 1, was the same as the Base conditions with the exception of a small channel around the southern side of Sheep Island and through Eastern Channel.

27. The results from Plan 1 indicate that a deepened channel around the southern part of Sheep Island and through Eastern Channel would not increase overall flushing. It would mainly redistribute the tracers.

28. As discussed in paragraphs 22 and 23, Plans 2 and 3 show faster decrease in tracer concentrations than the Base condition. This indicates that the AIWW could cause decreased flushing. However, as shown in paragraphs 24 and 25, there is no real difference in tidal prism between the plans and the Base condition. Also, both the Base and Plan 1 conditions initially have more tracer mass. The shapes of the cumulative flushing curves (Figure 41) indicate that overall flushing rate is the same for all conditions, with the only difference being the time that rapid flushing begins.

29. The results suggest that there are three zones with characteristic flushing rates. A central zone which flushes at different rates depending on geometry and seaward and landward zones which flush at the same rate for all geometries. The tracer levels in the seaward and landward zones will depend on the levels in the central zone. The central zone difference in rate is due to the added tracer mass and volume of the AIWW.

30. Although the tracer simulations here are not verified, the results indicate that the AIWW does not contribute significantly to a degradation in water circulation.

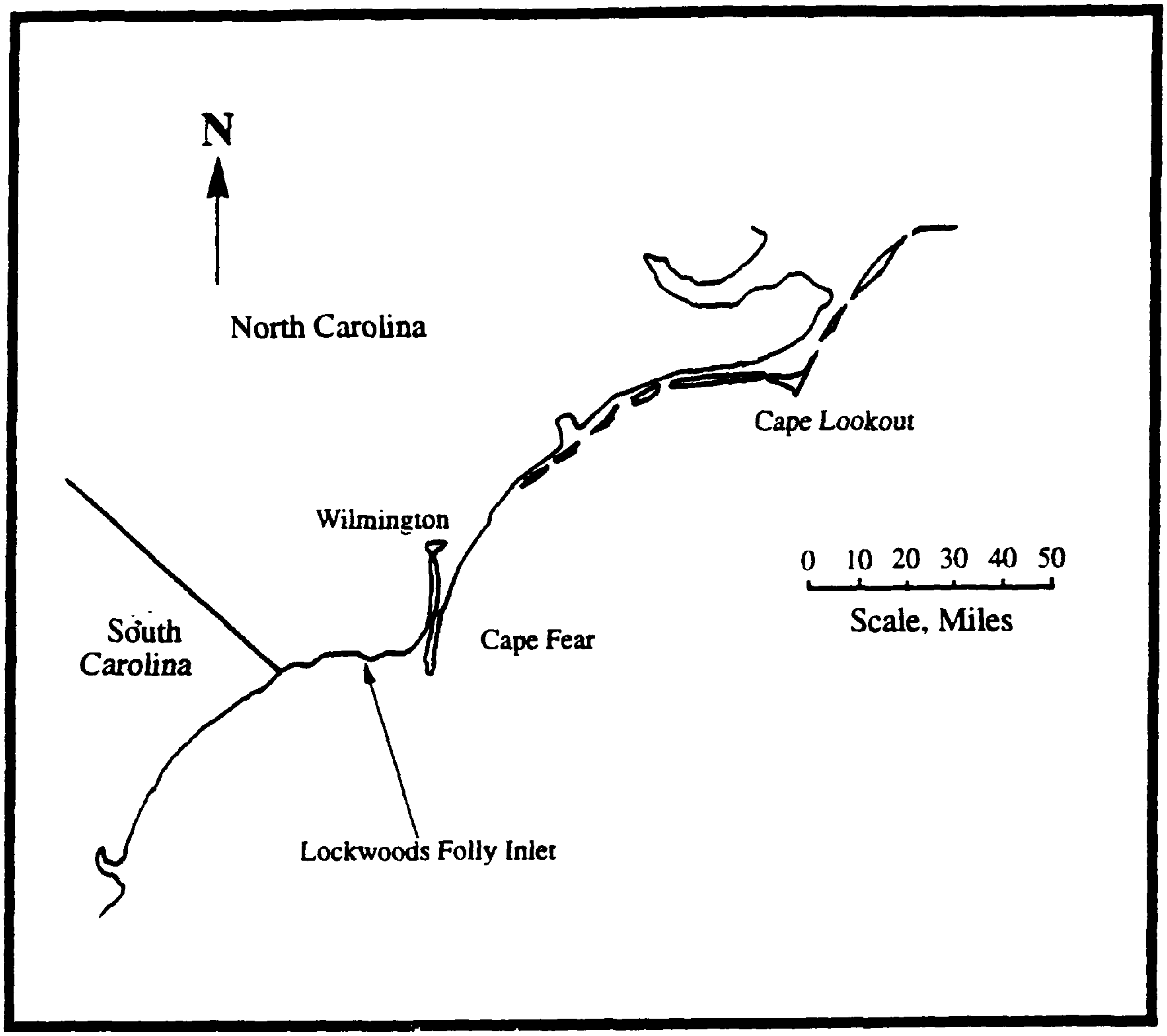

Figure 1. Location map for Lockwoods Folly Inlet

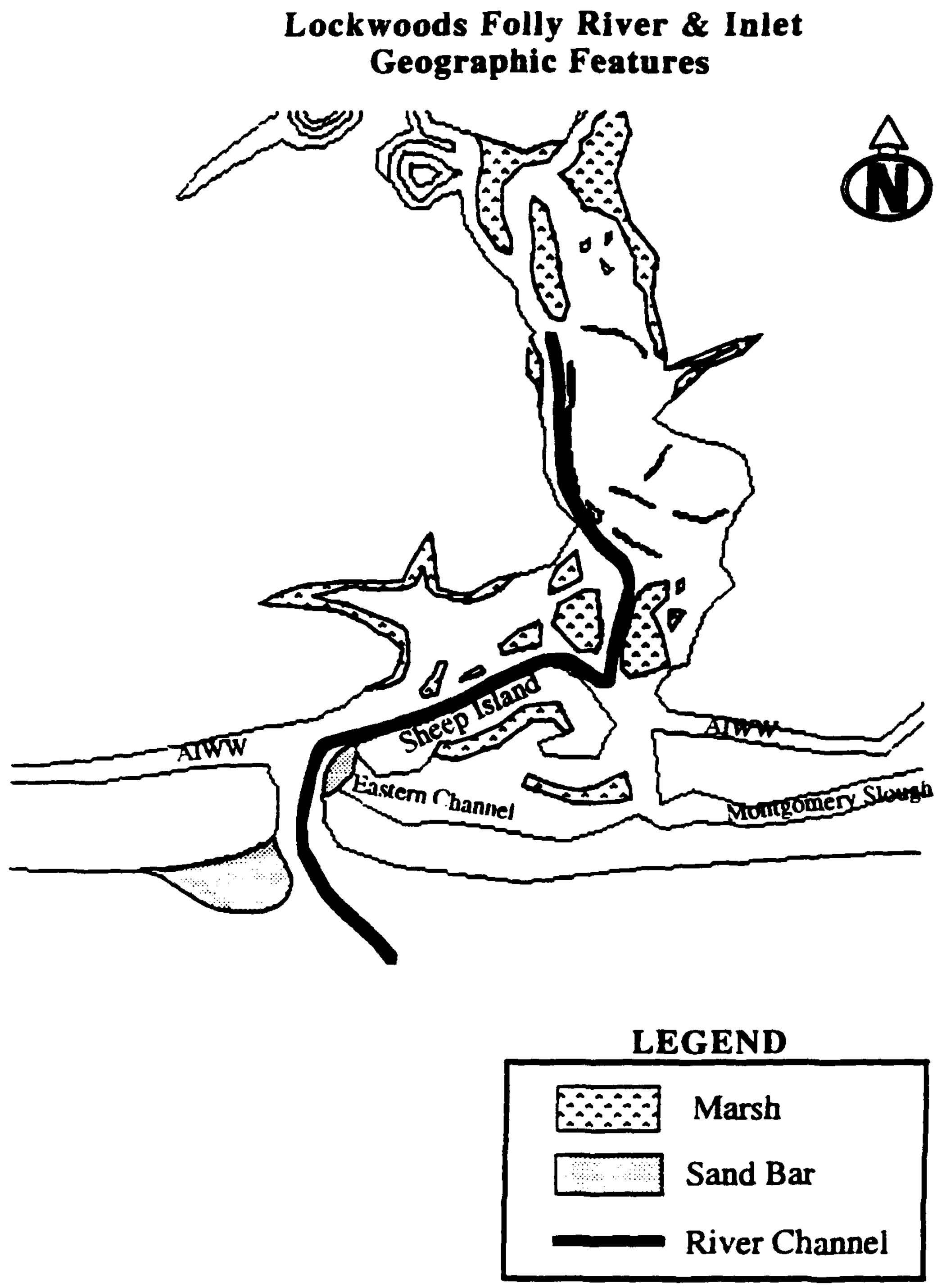

Figure 2. Location map of prominent features

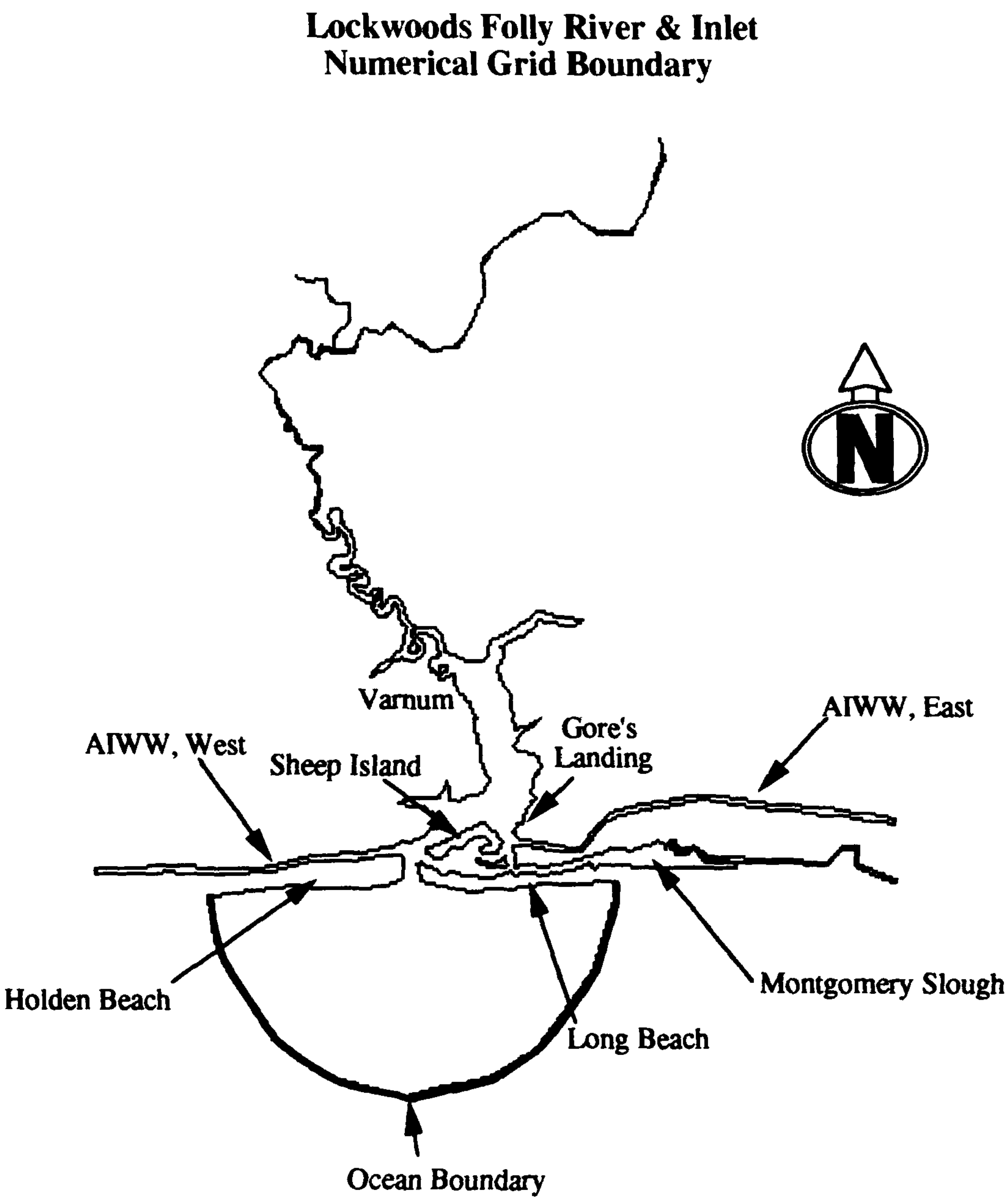

Figure 3. Base geometry numerical grid boundary

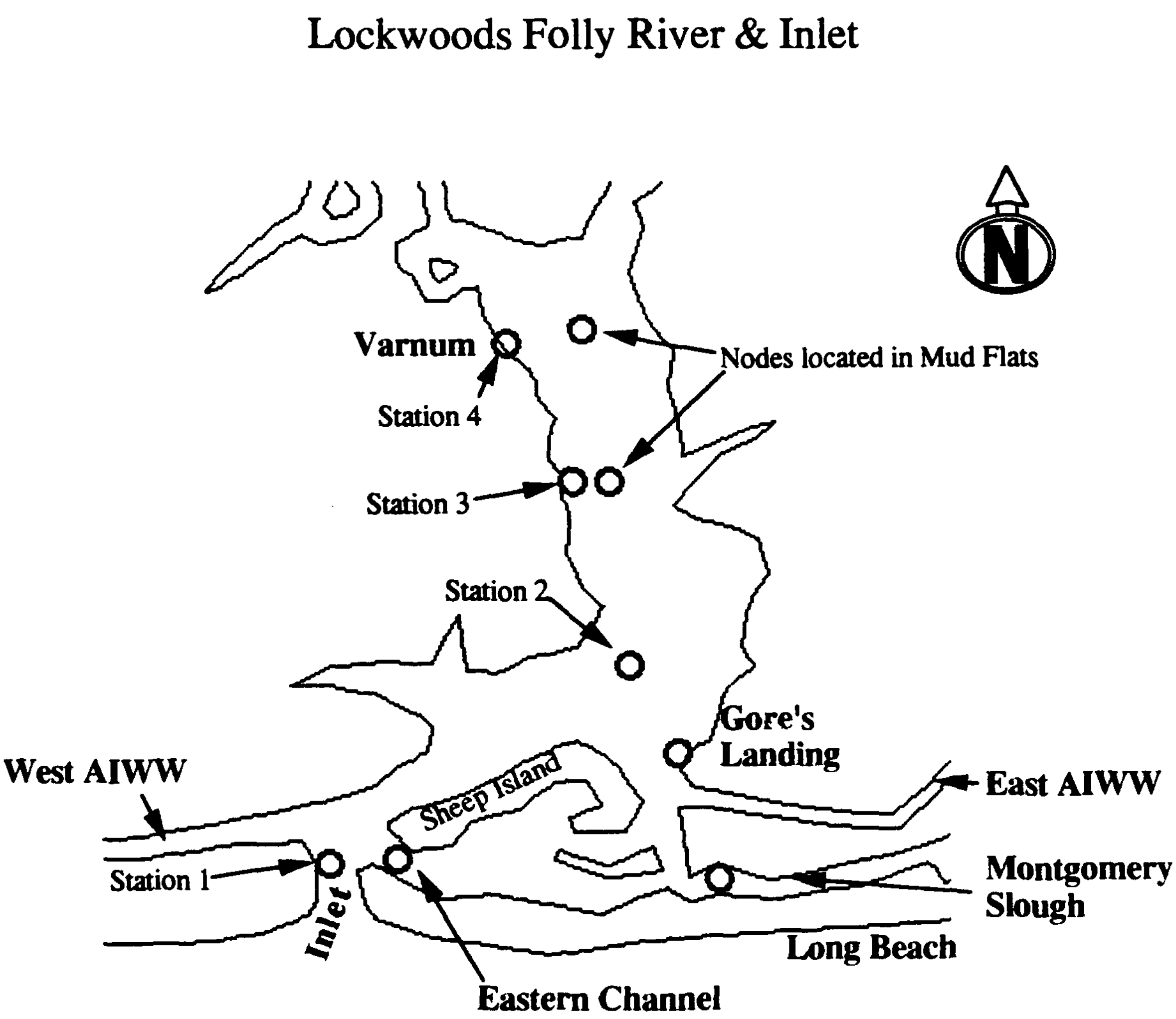

Figure 4. Station and selected node locations

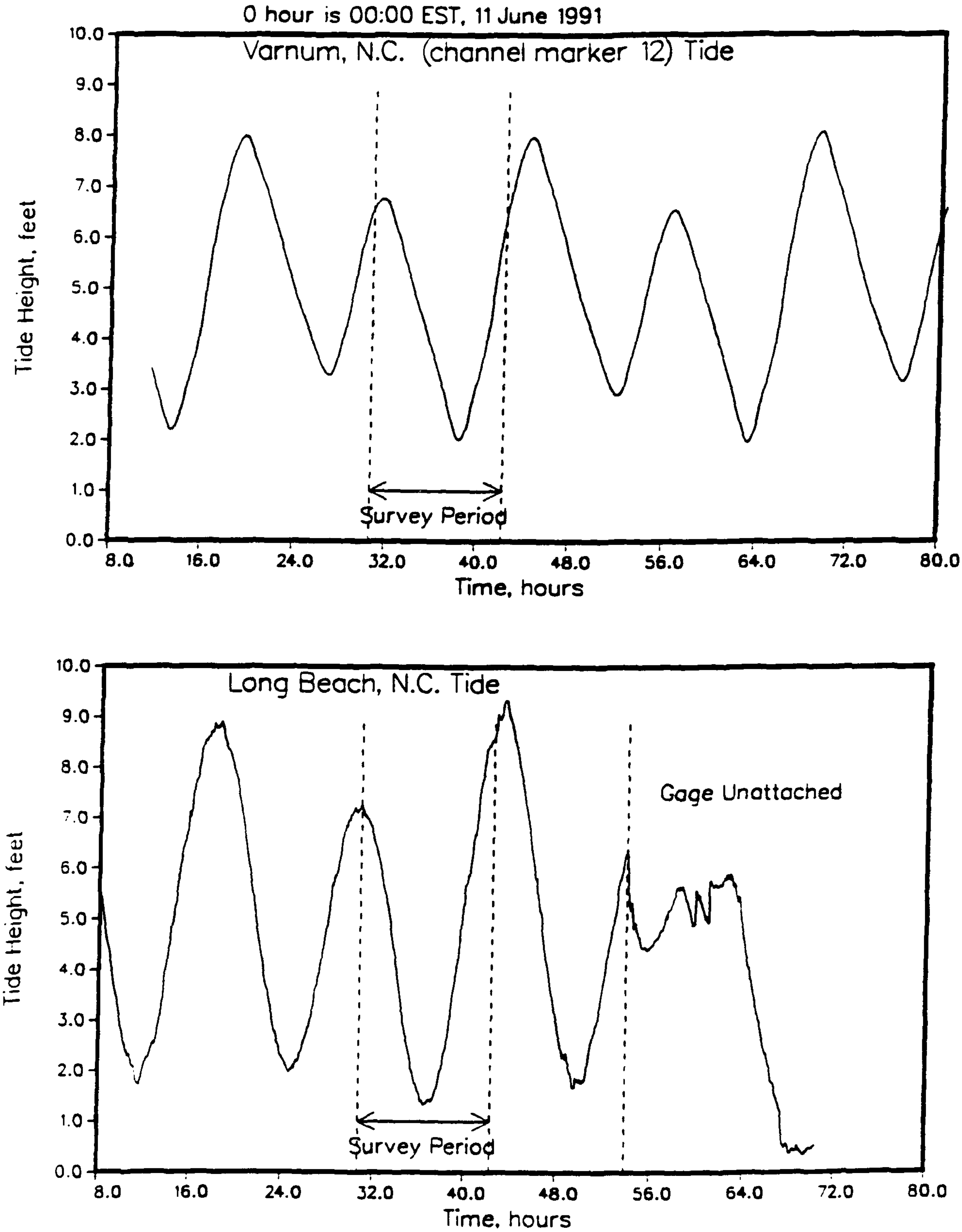

Figure 5. Water surface elevations, 11-14 June 1991

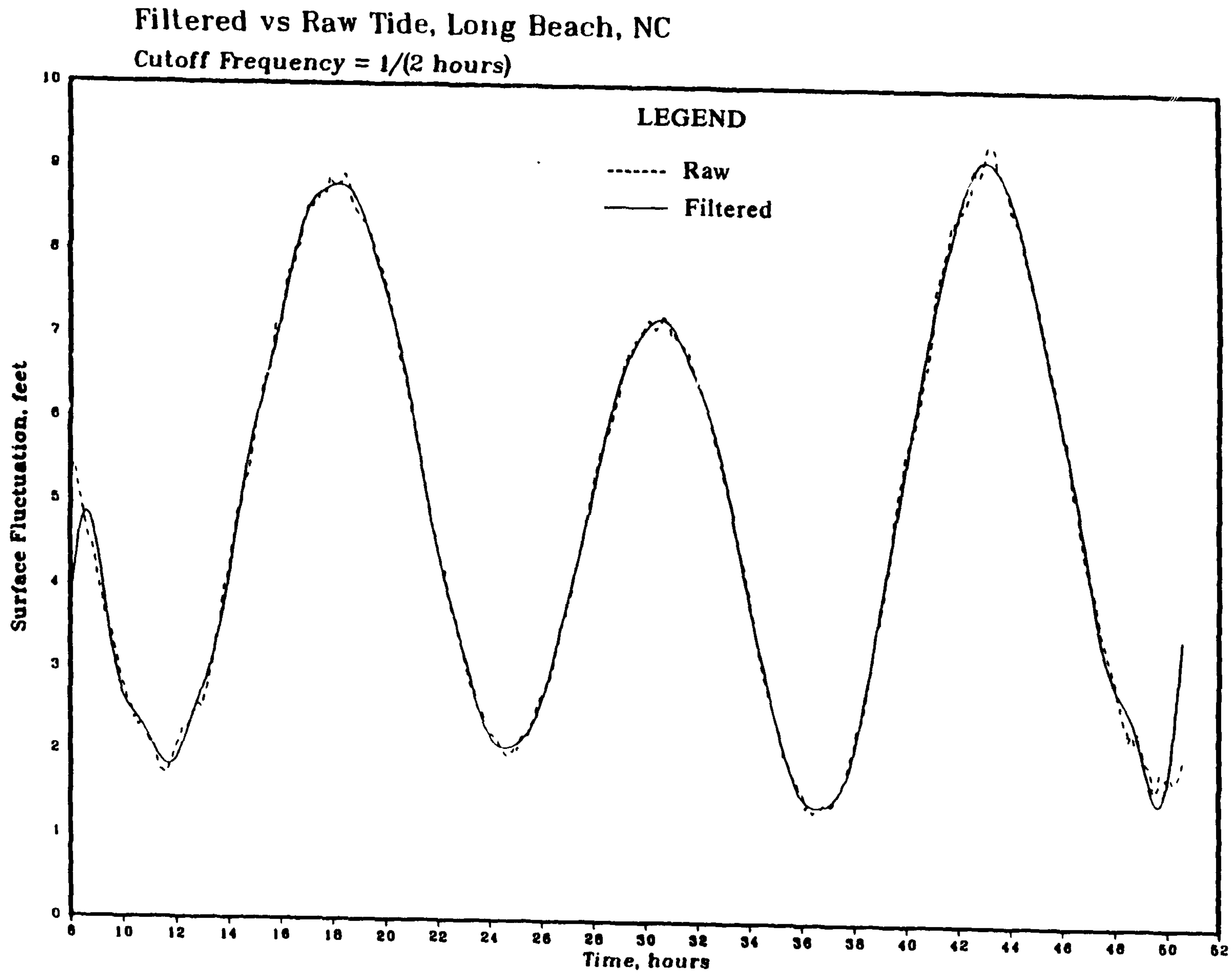

Figure 6. Filtered tide data, Long Beach, NC, 11-14 June 1991

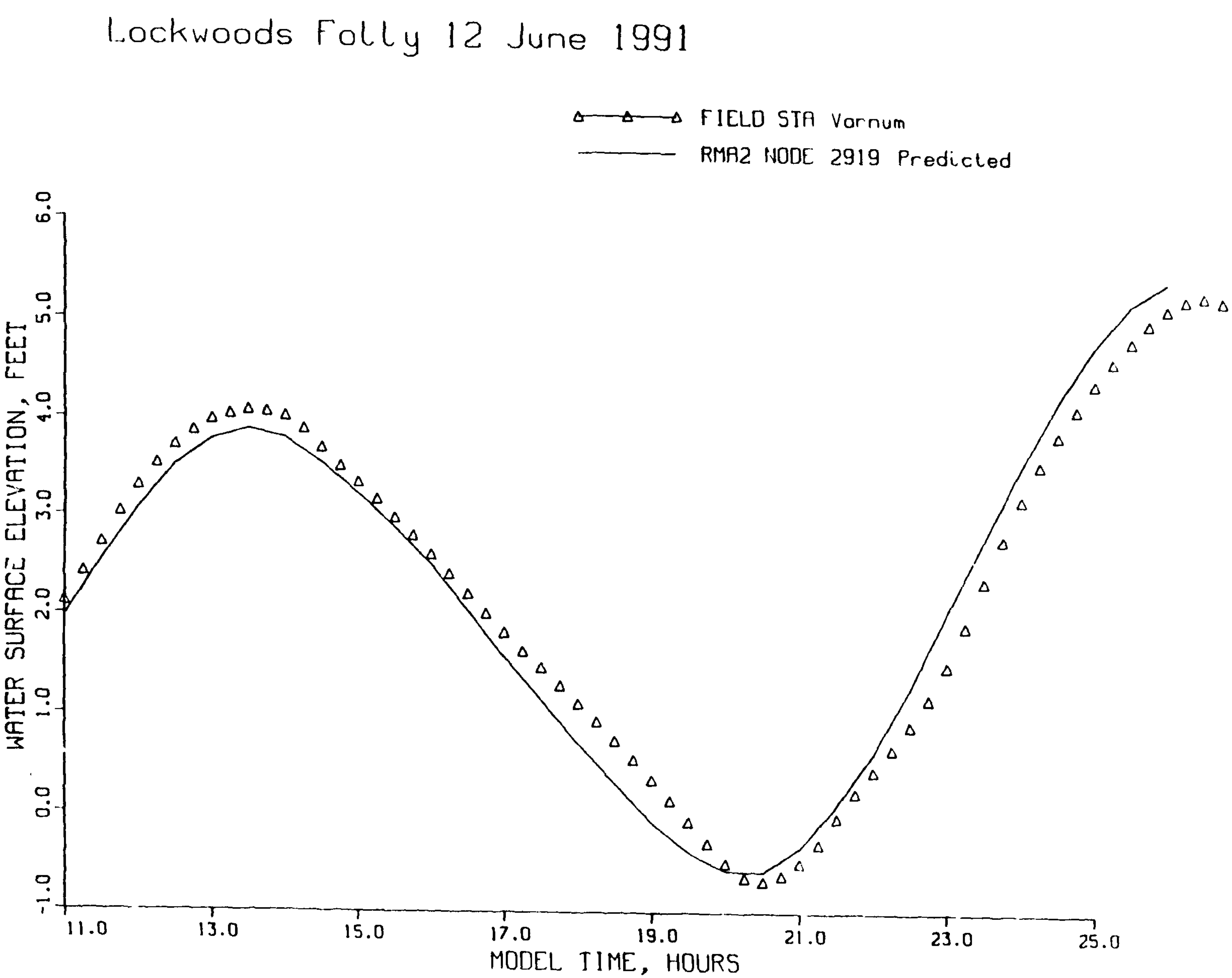

Figure 7. Model versus field data, Varnum, NC

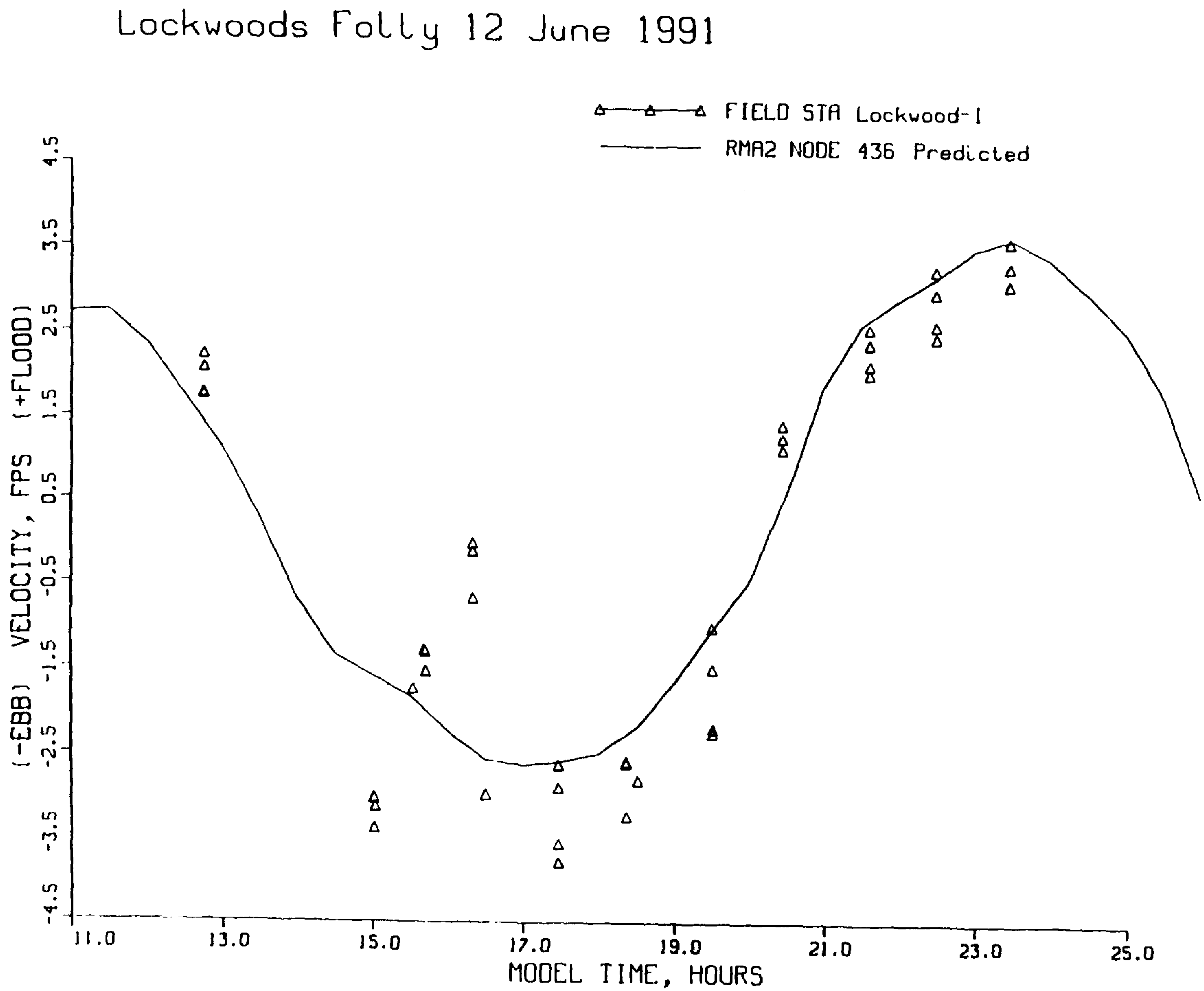

Figure 8. Model versus field data, Lockwoods Folly Inlet, Station 1

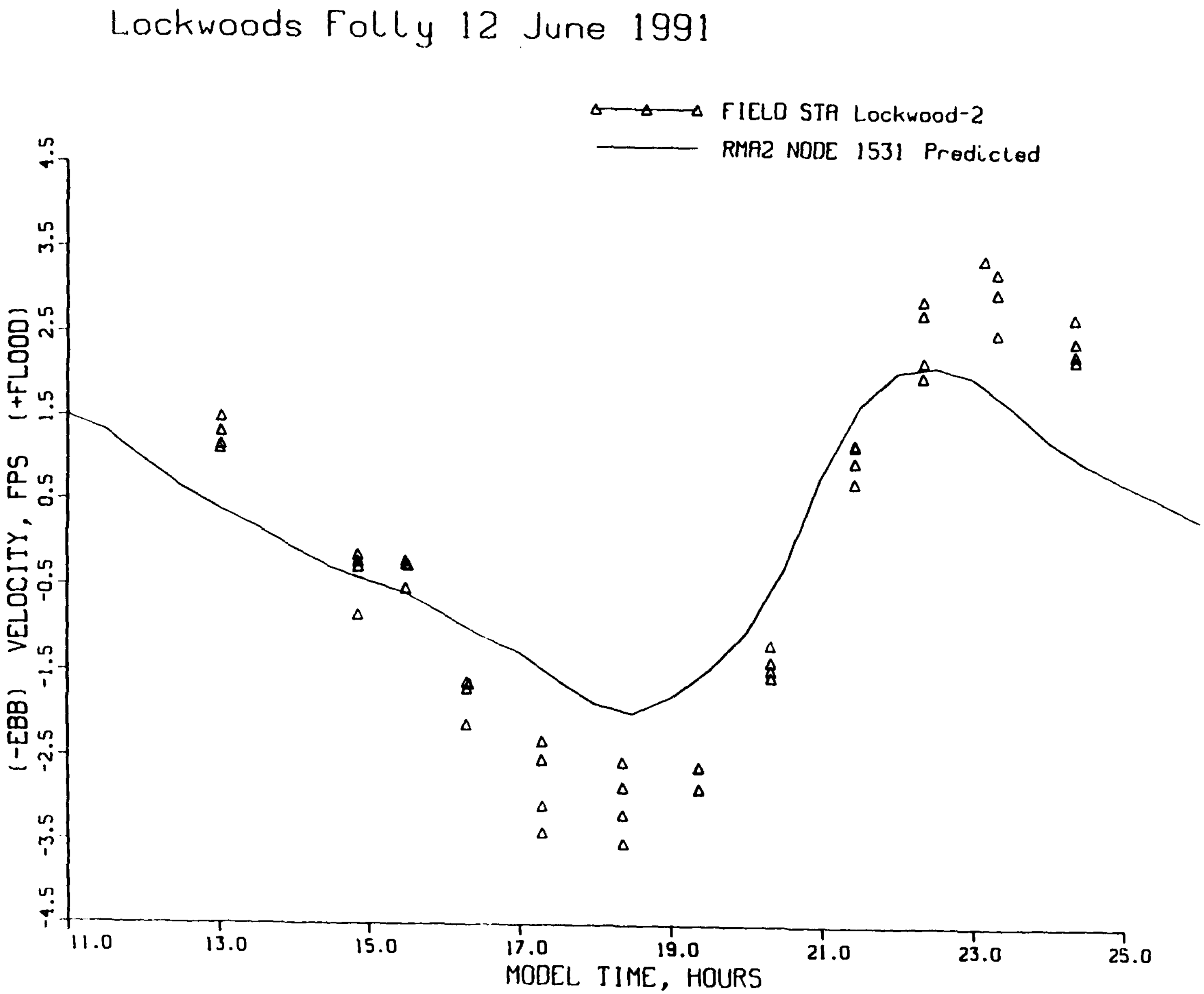

Figure 9. Model versus field data, Channel Marker 4, Station 2

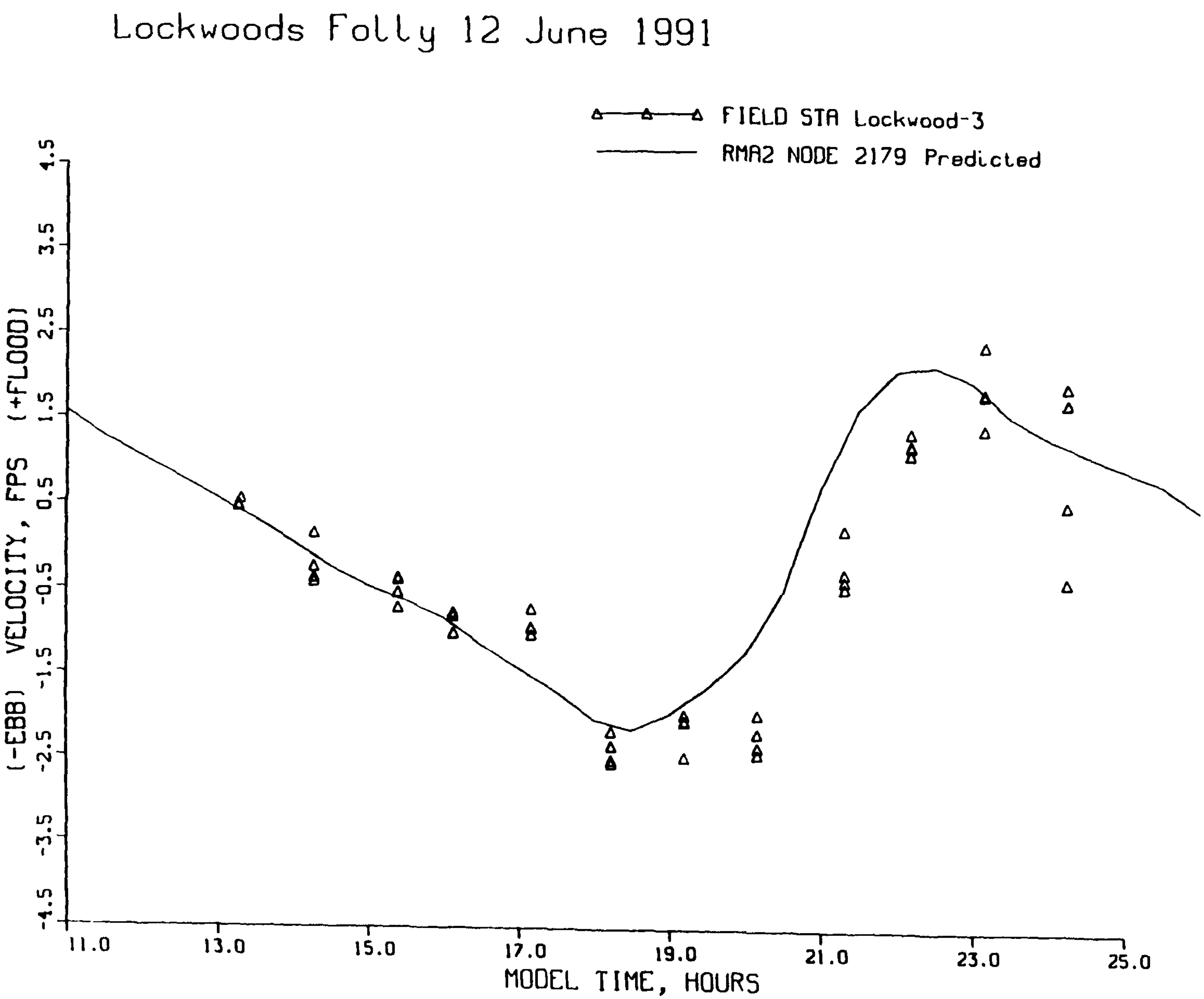

Figure 10. Model versus field data, Channel Marker 8, Station 3

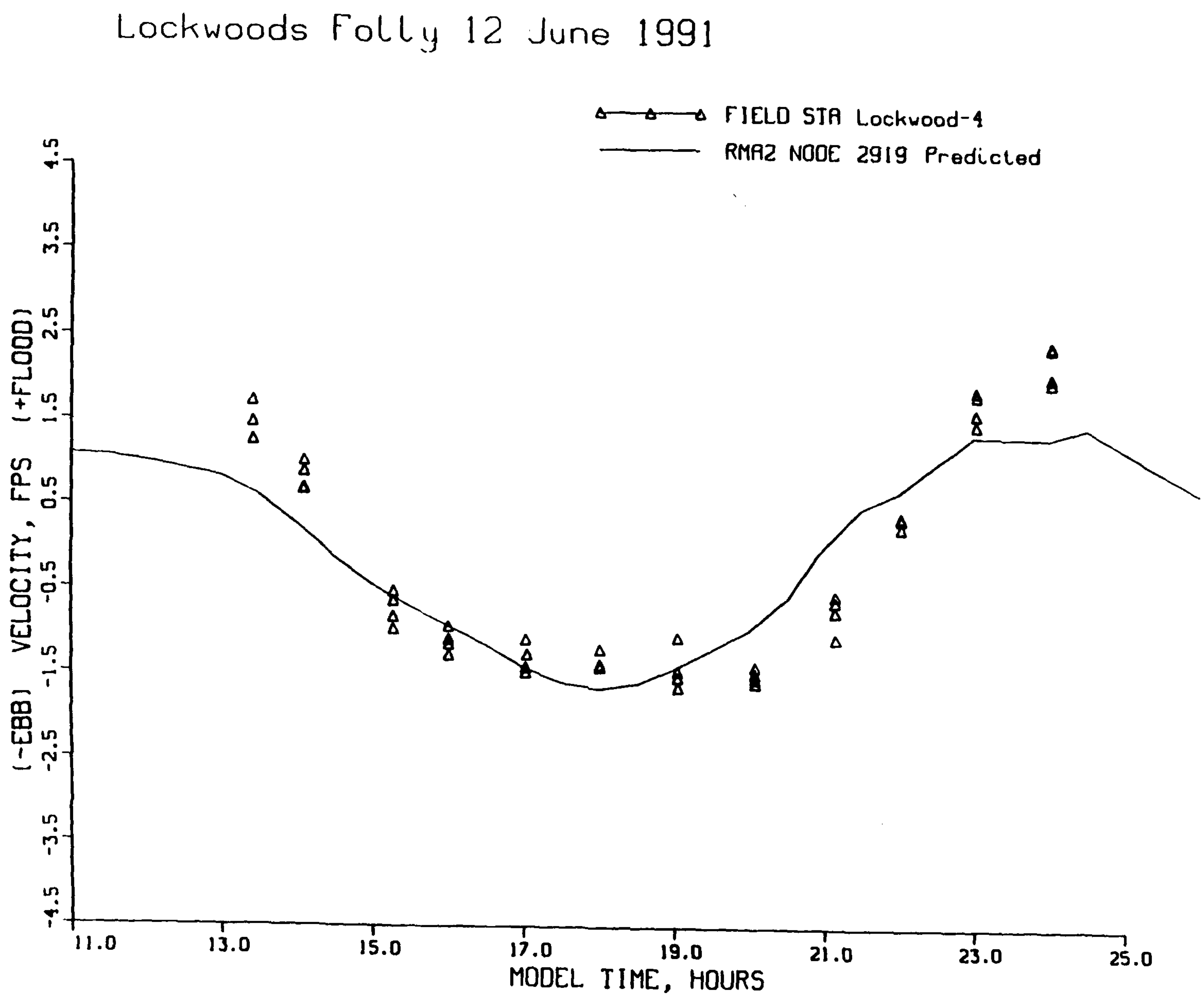

Figure 11. Model versus field data, Channel Marker 12, Station 4

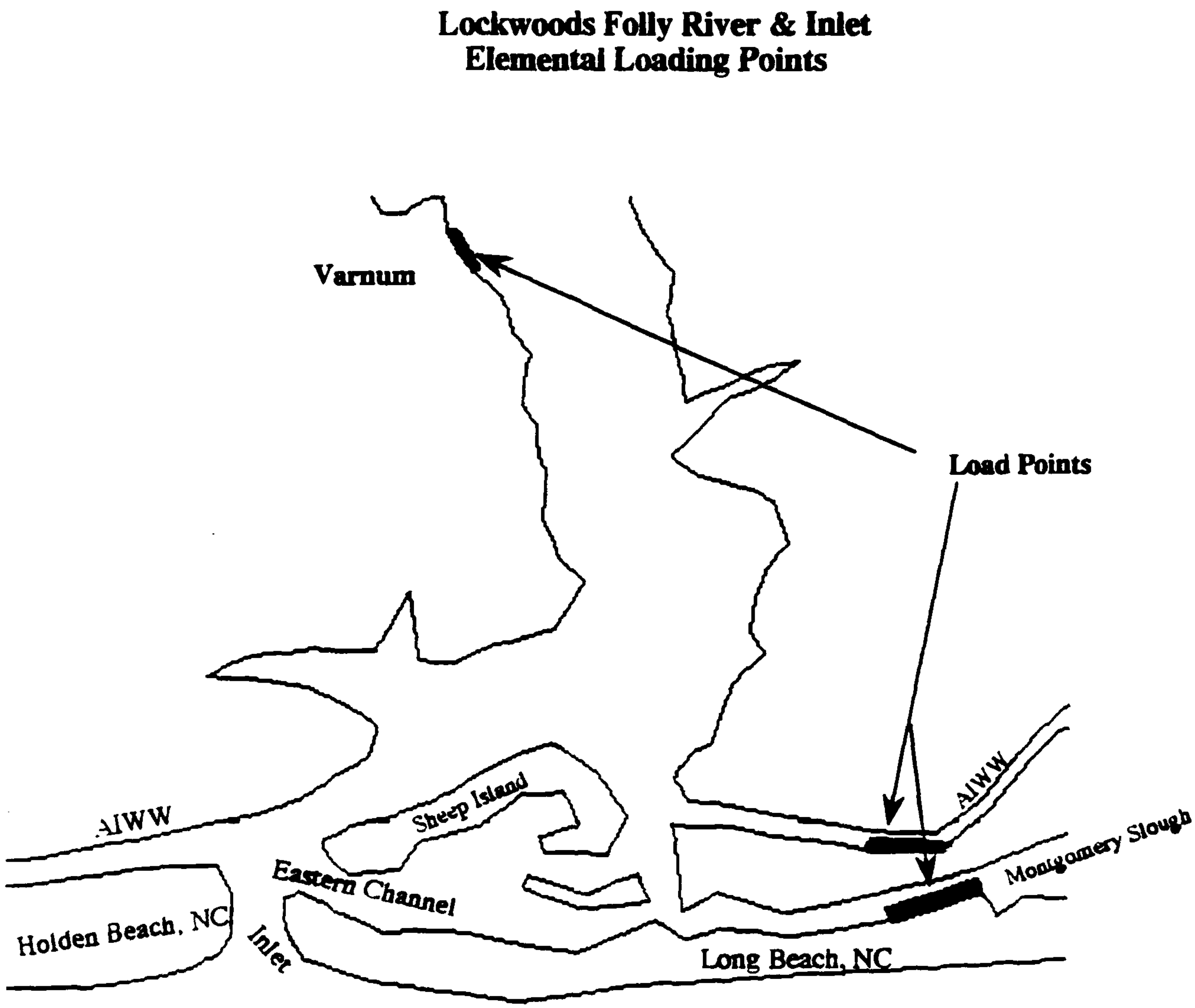

Figure 12. Tracer source locations

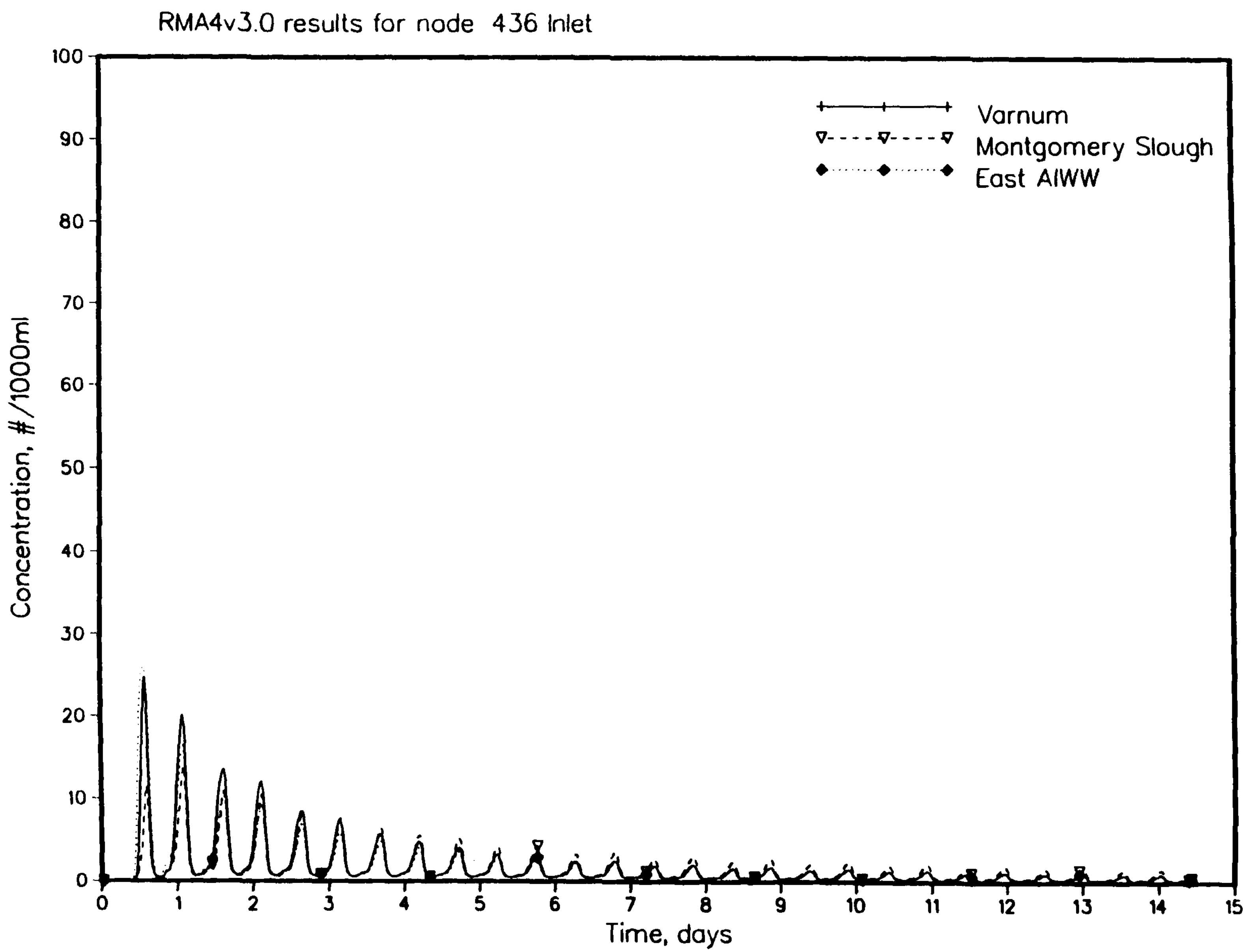

Figure 13. Tracer levels for three sources, Lockwoods Folly Inlet

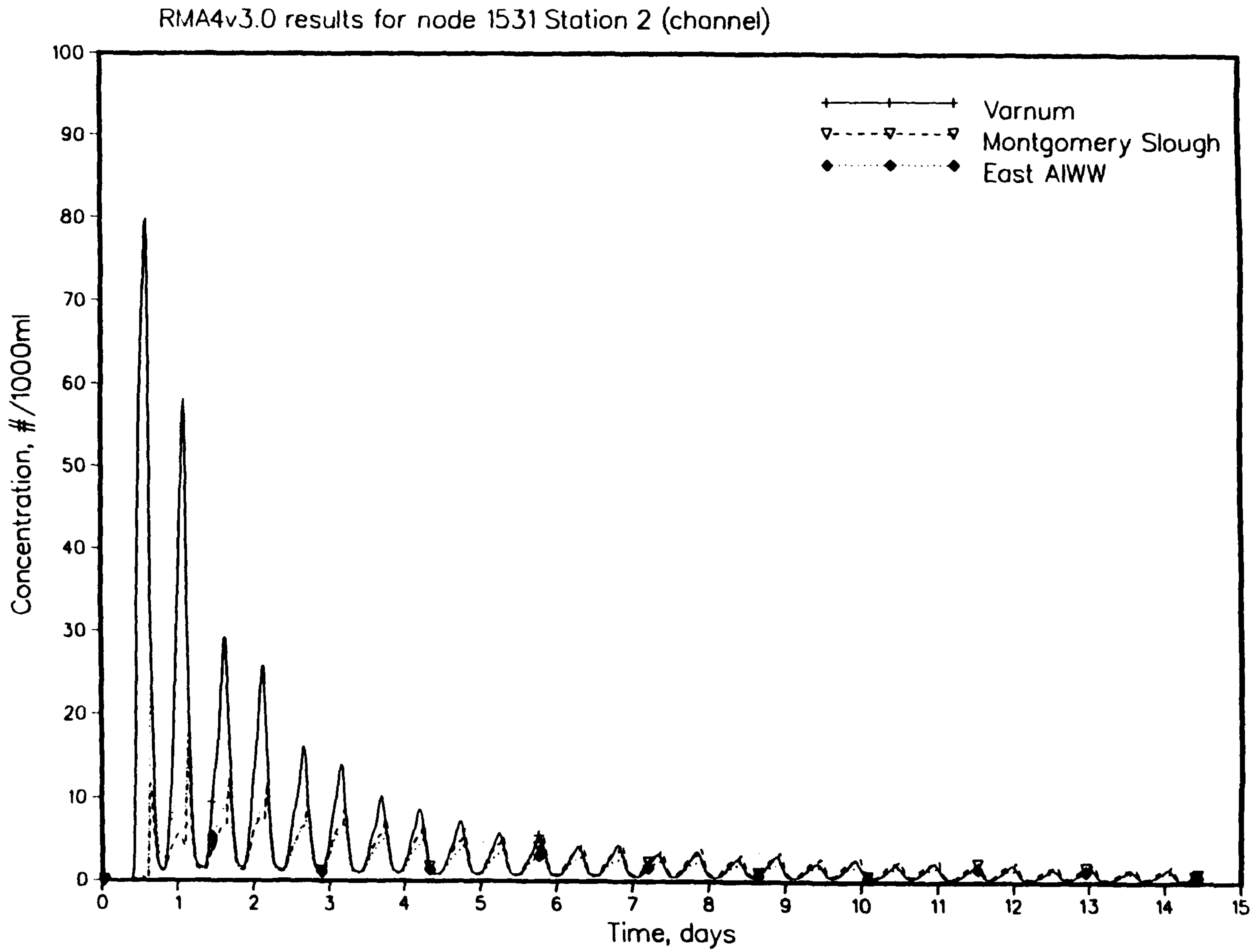

Figure 14. Tracer levels for three sources, Station 2

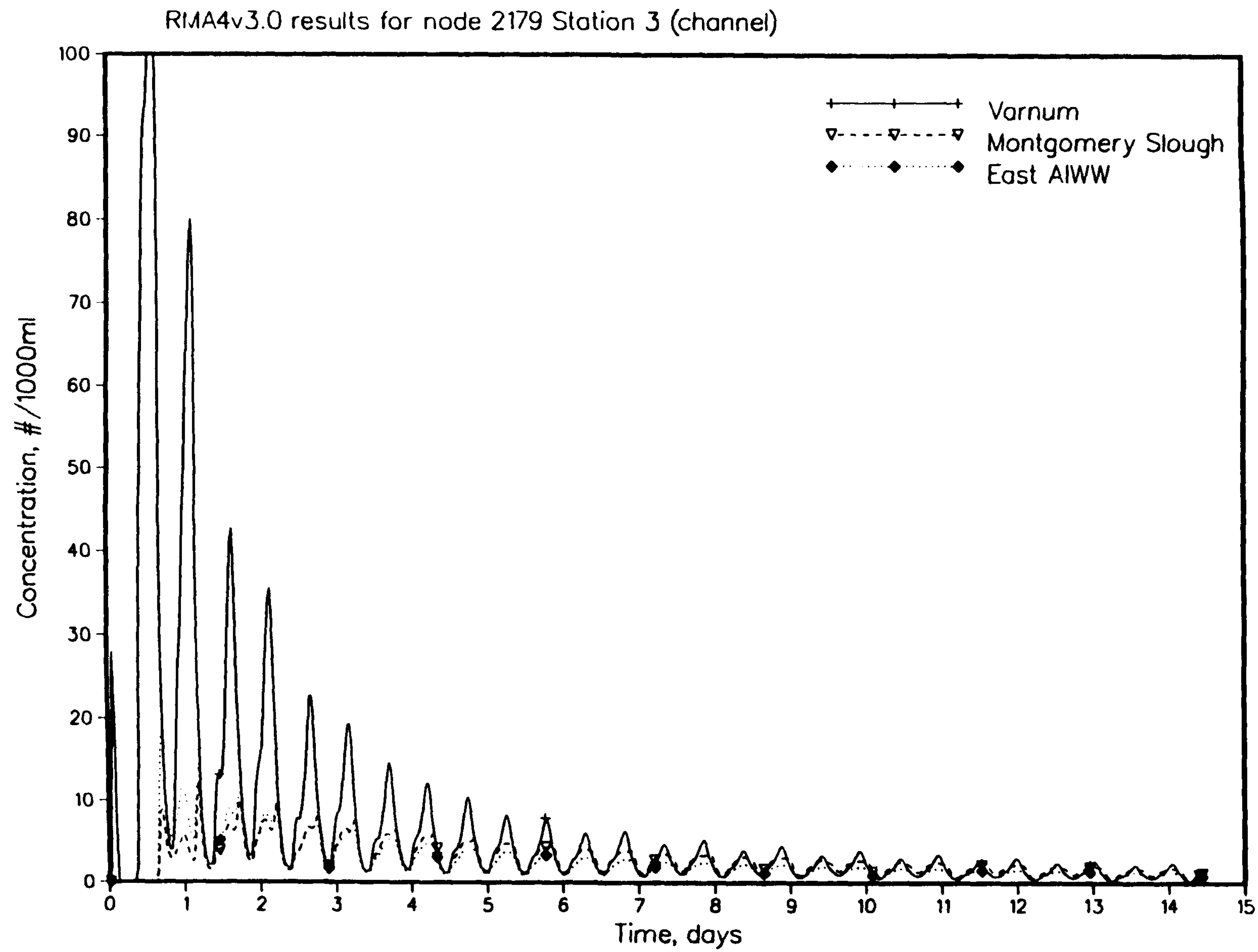

Figure 15. Tracer levels for three sources, Station 3

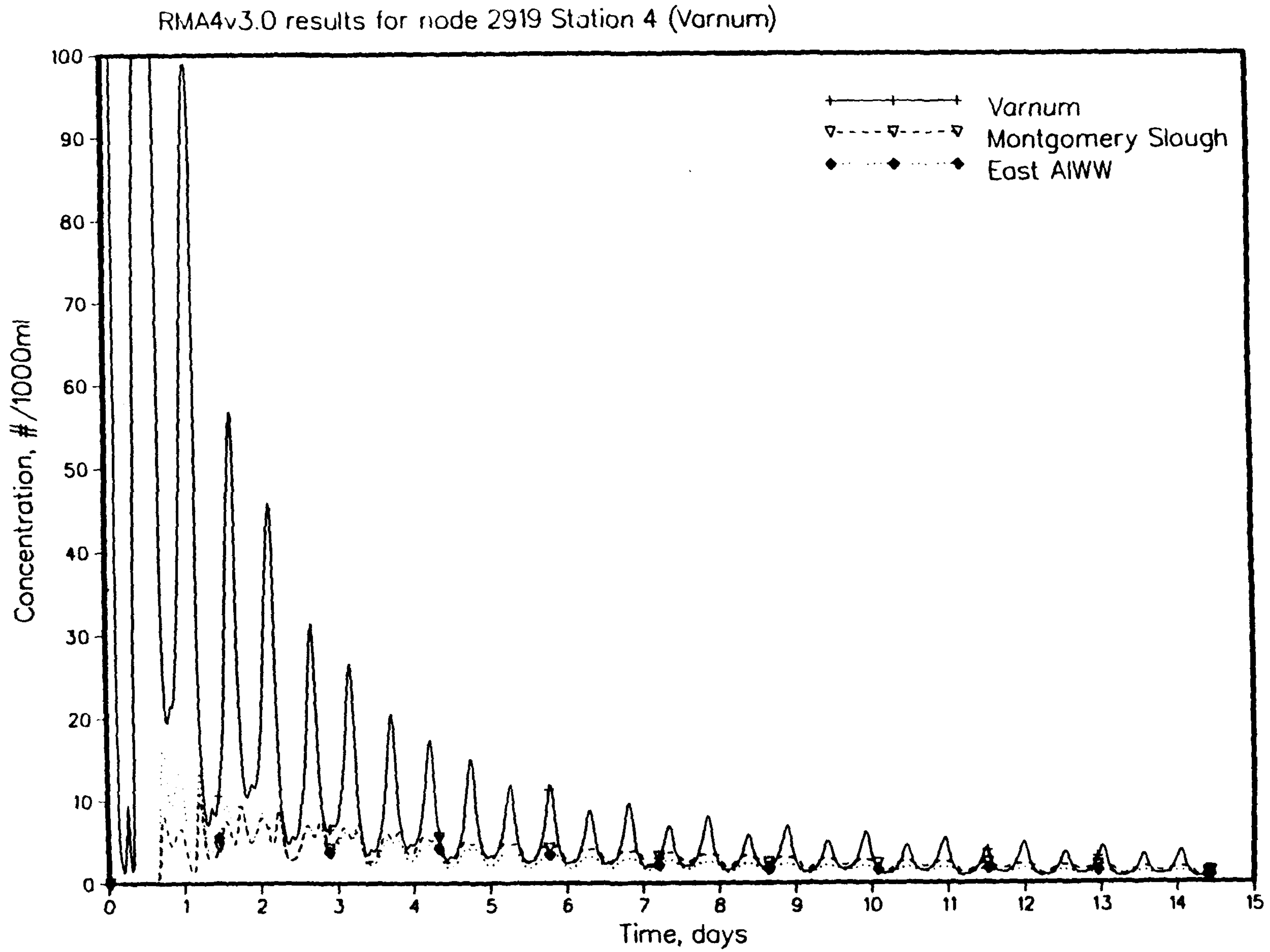

Figure 16. Tracer levels for three sources, Station 4

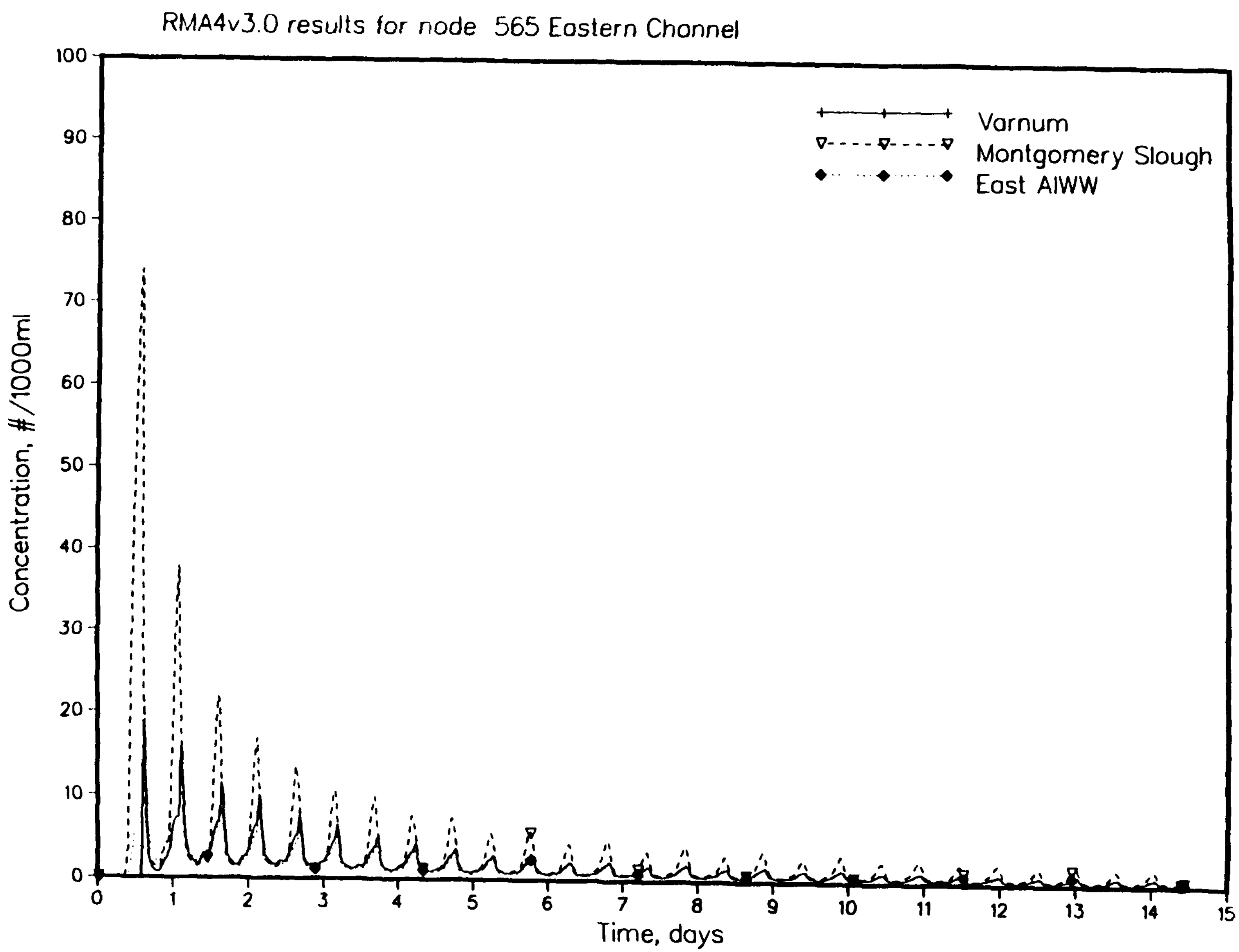

Figure 17. Tracer levels for three sources, Eastern Channel

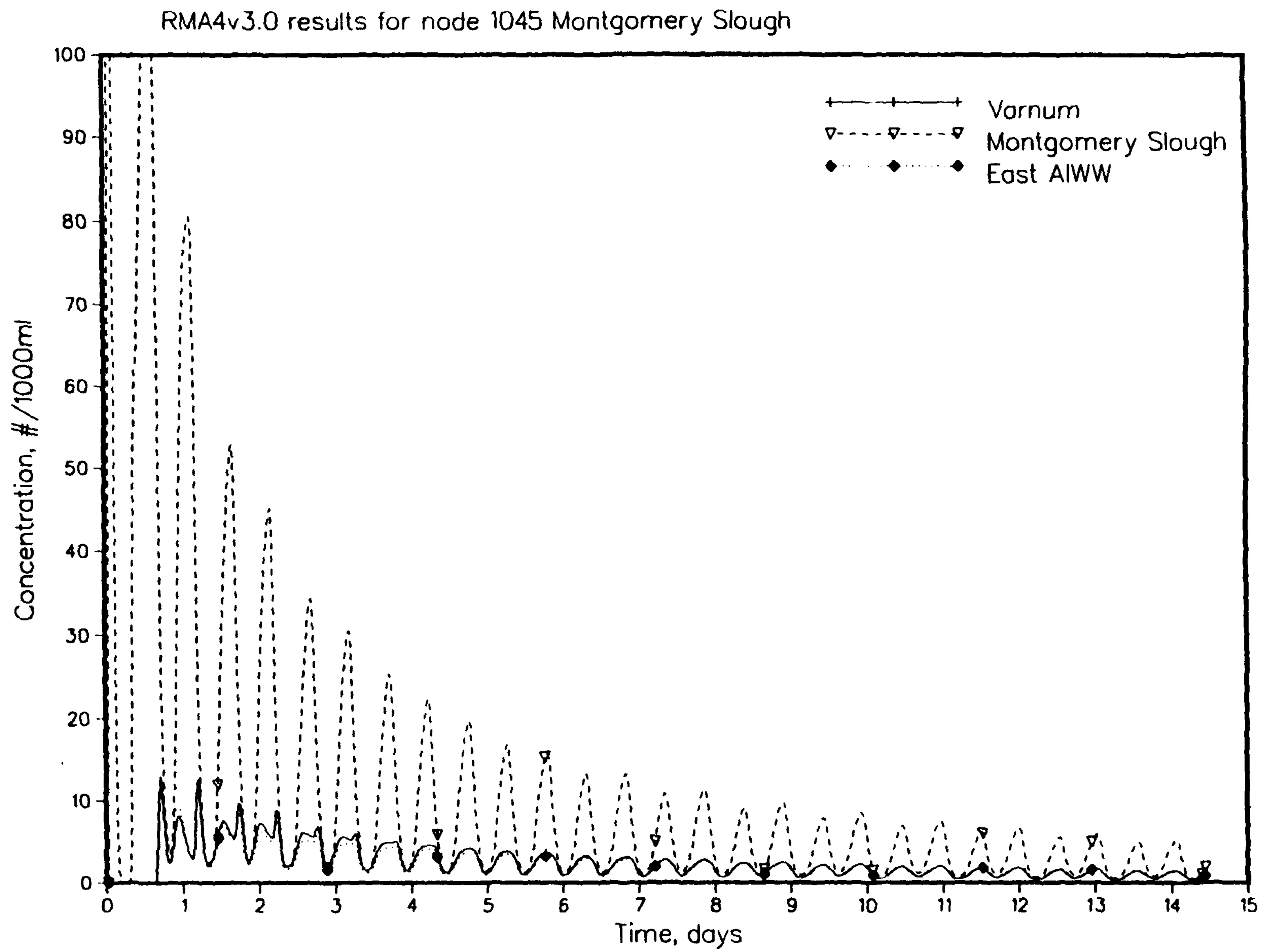

Figure 18. Tracer levels for three sources, Montgomery Slough

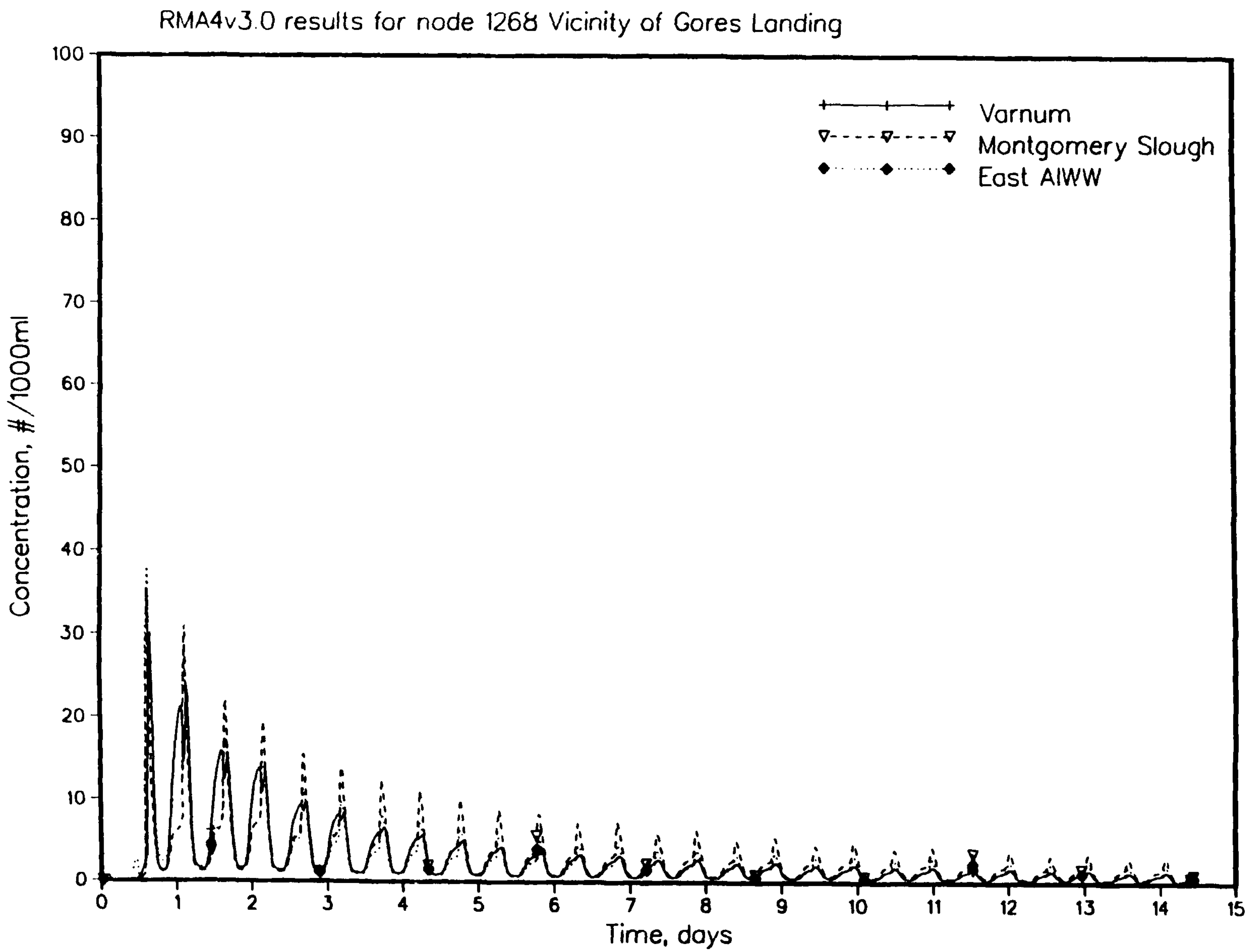

Figure 19. Tracer levels for three sources, vicinity of Gores Landing

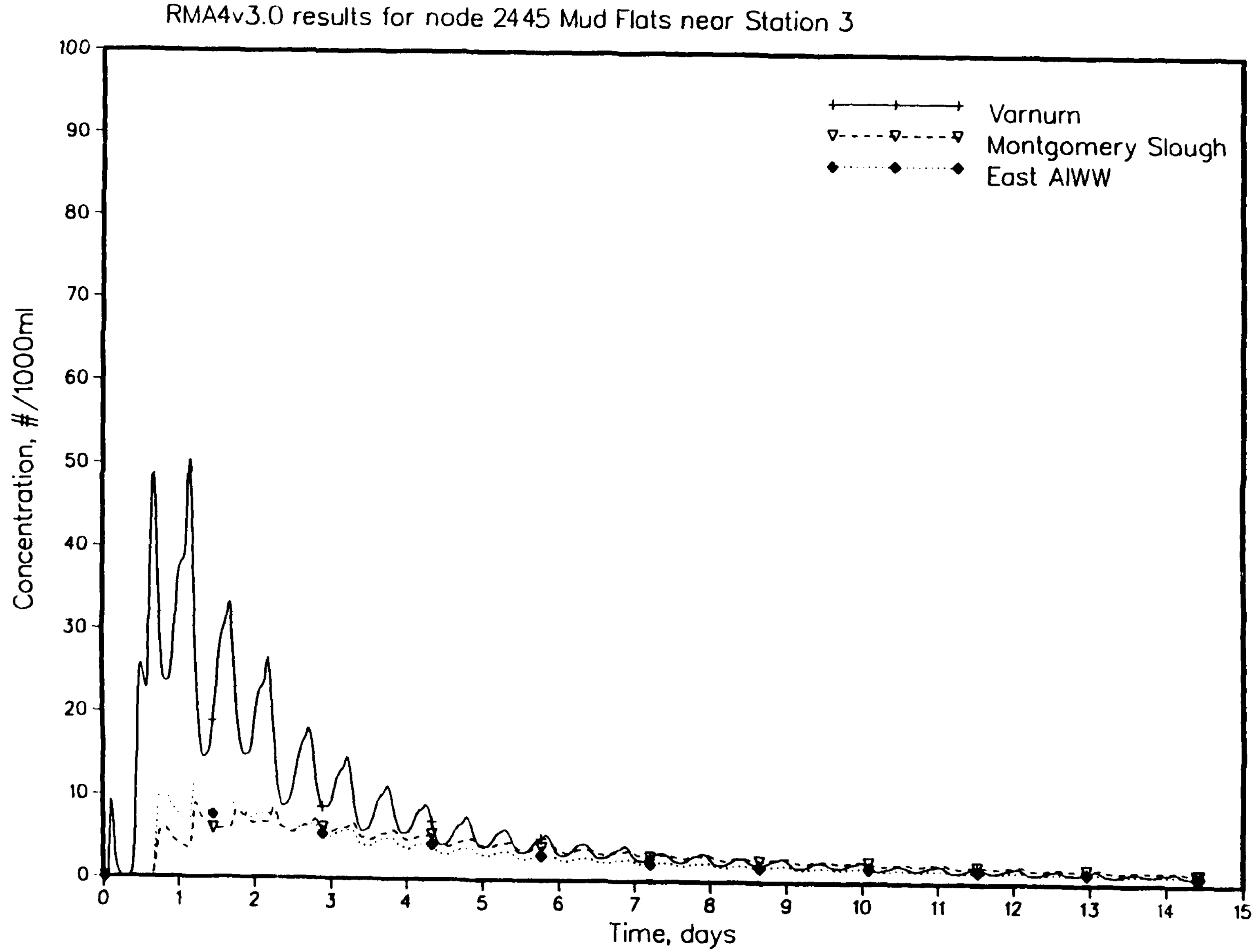

Figure 20. Tracer levels for three sources, Mud Flats near Station 3

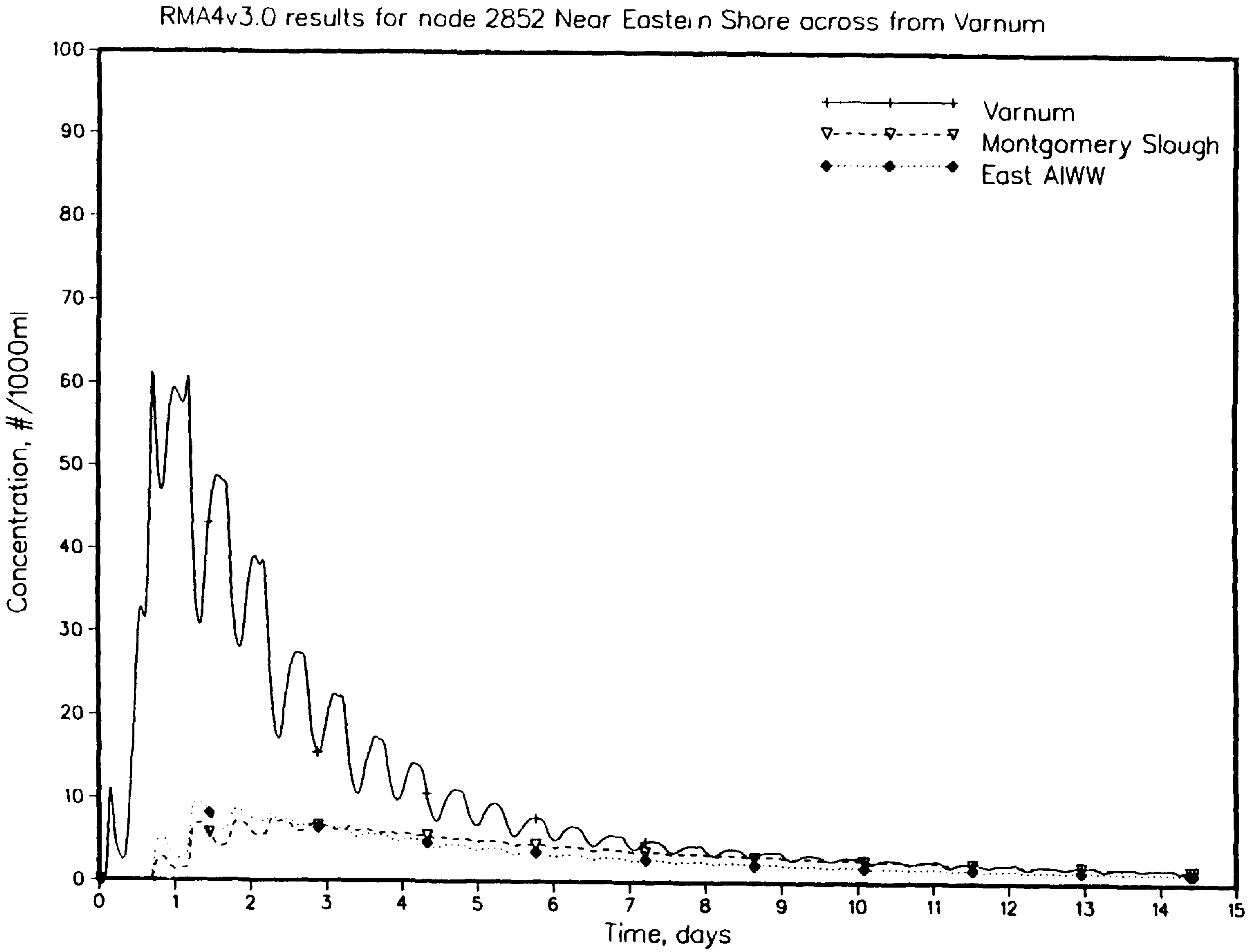

Figure 21. Tracer levels for three sources, Mud Flats near Station 4

Figure 22. Fifty percent reduction time, base plan

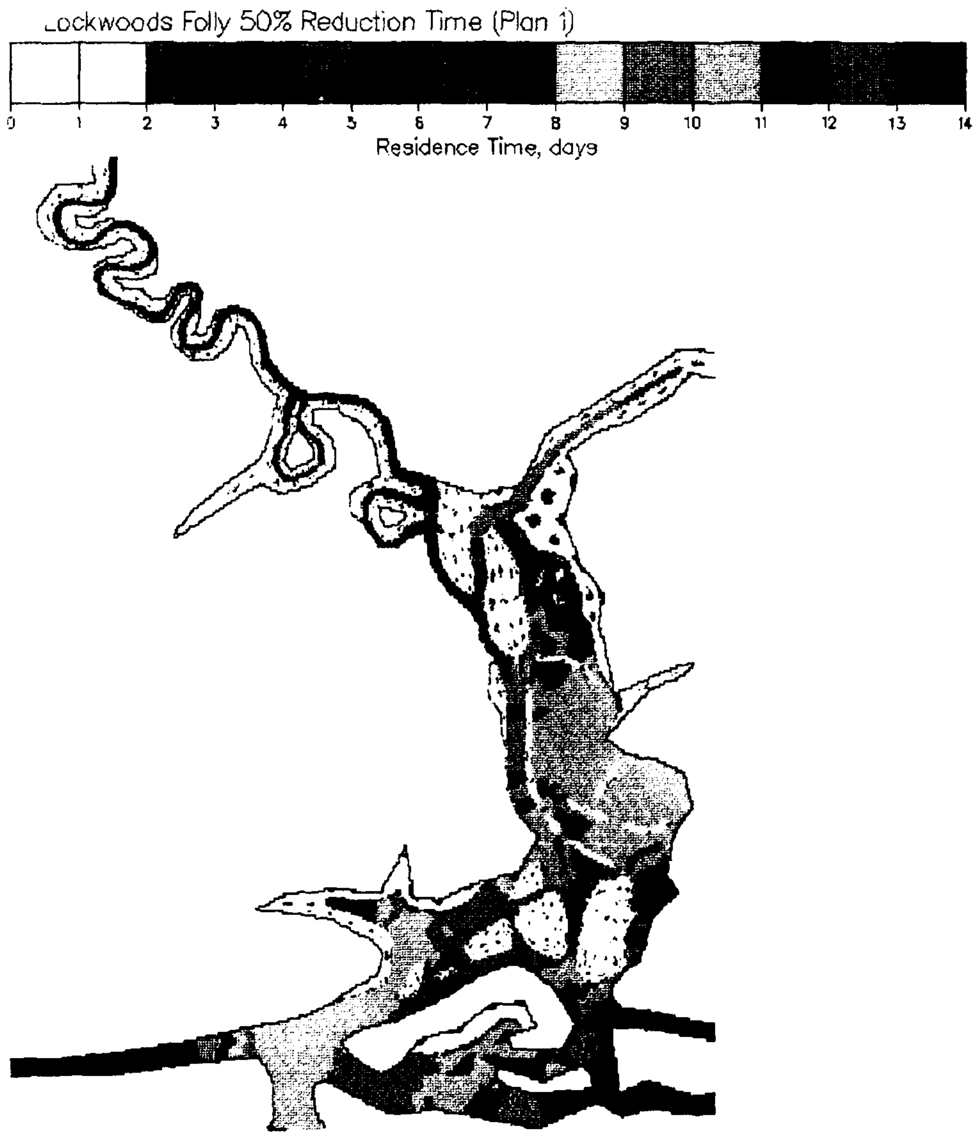

Figure 23. Fifty percent reduction time, Plan 1

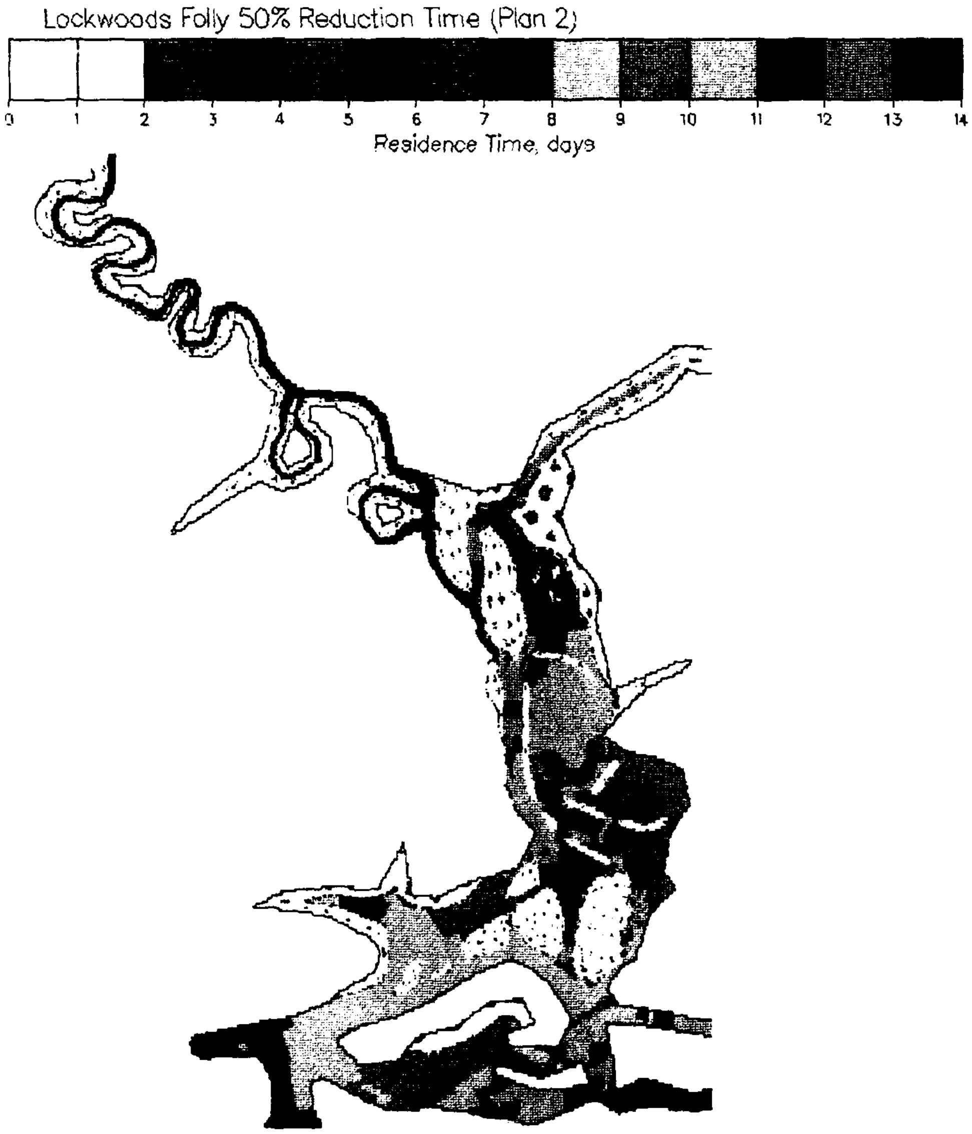

Figure 24. Fifty percent reduction time, Plan 2

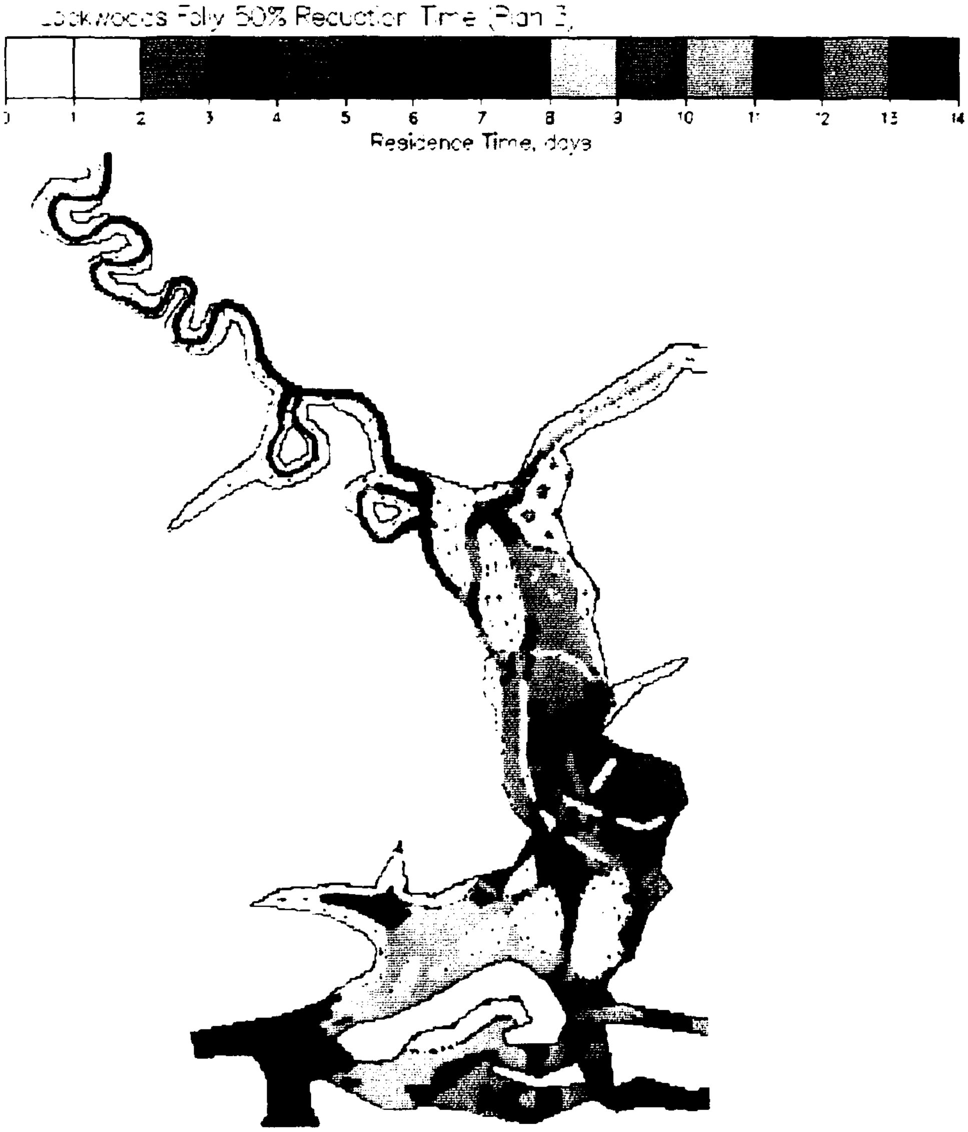

Figure 25. Fifty percent reduction time, Plan 3

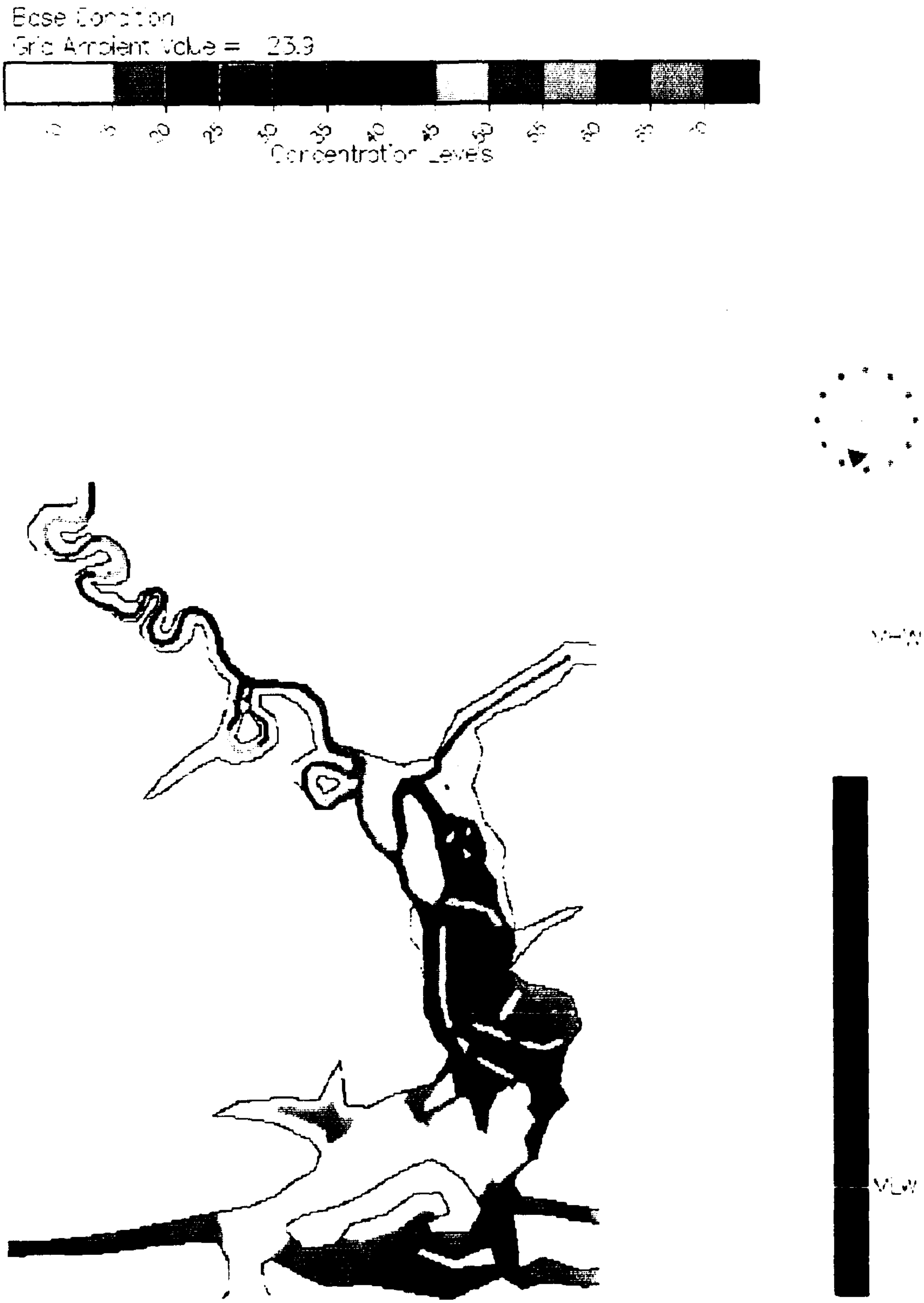

Figure 26. Tracer levels, base condition, high tide, Day 14

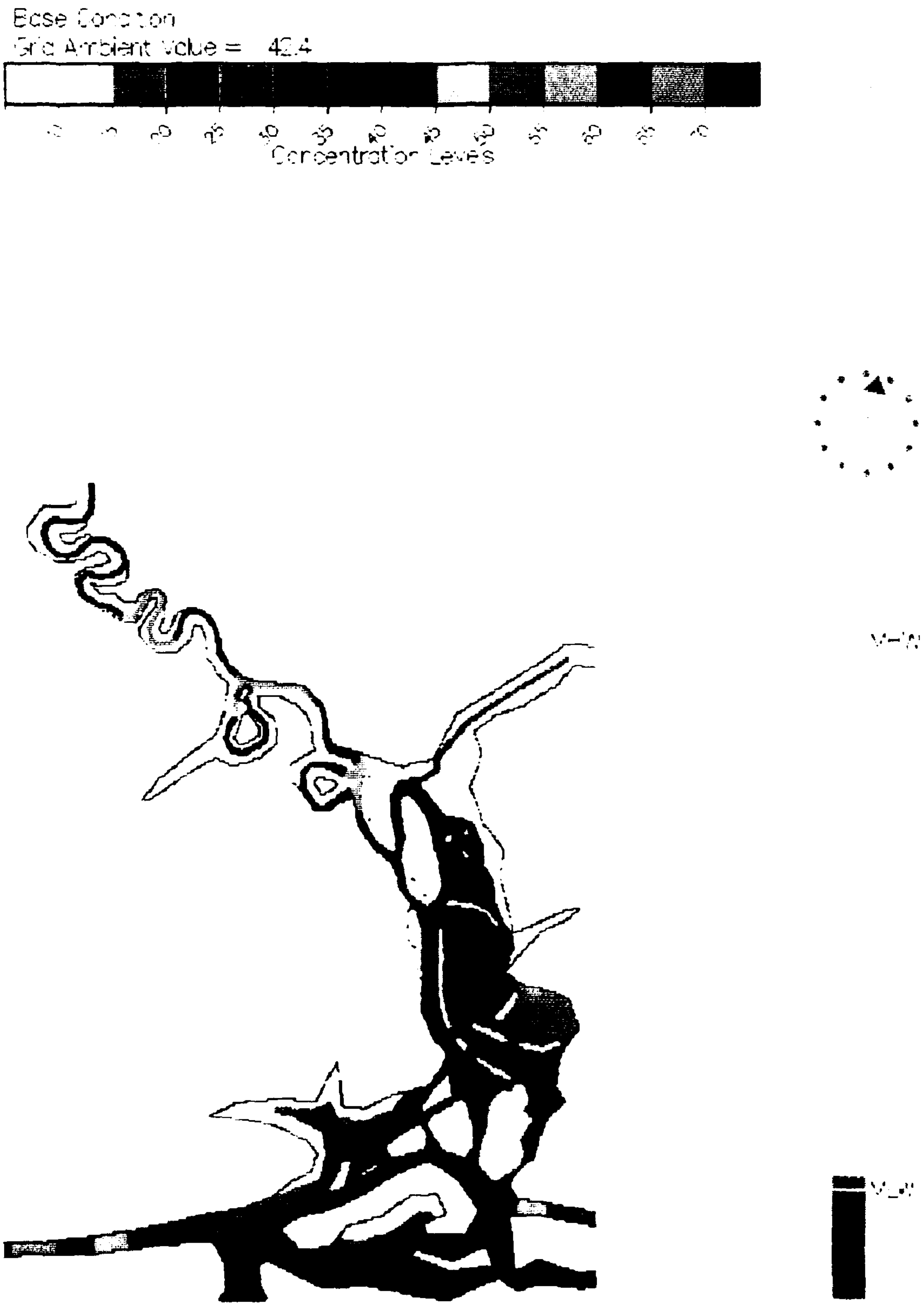

Figure 27. Tracer levels, base condition, low tide, Day 15

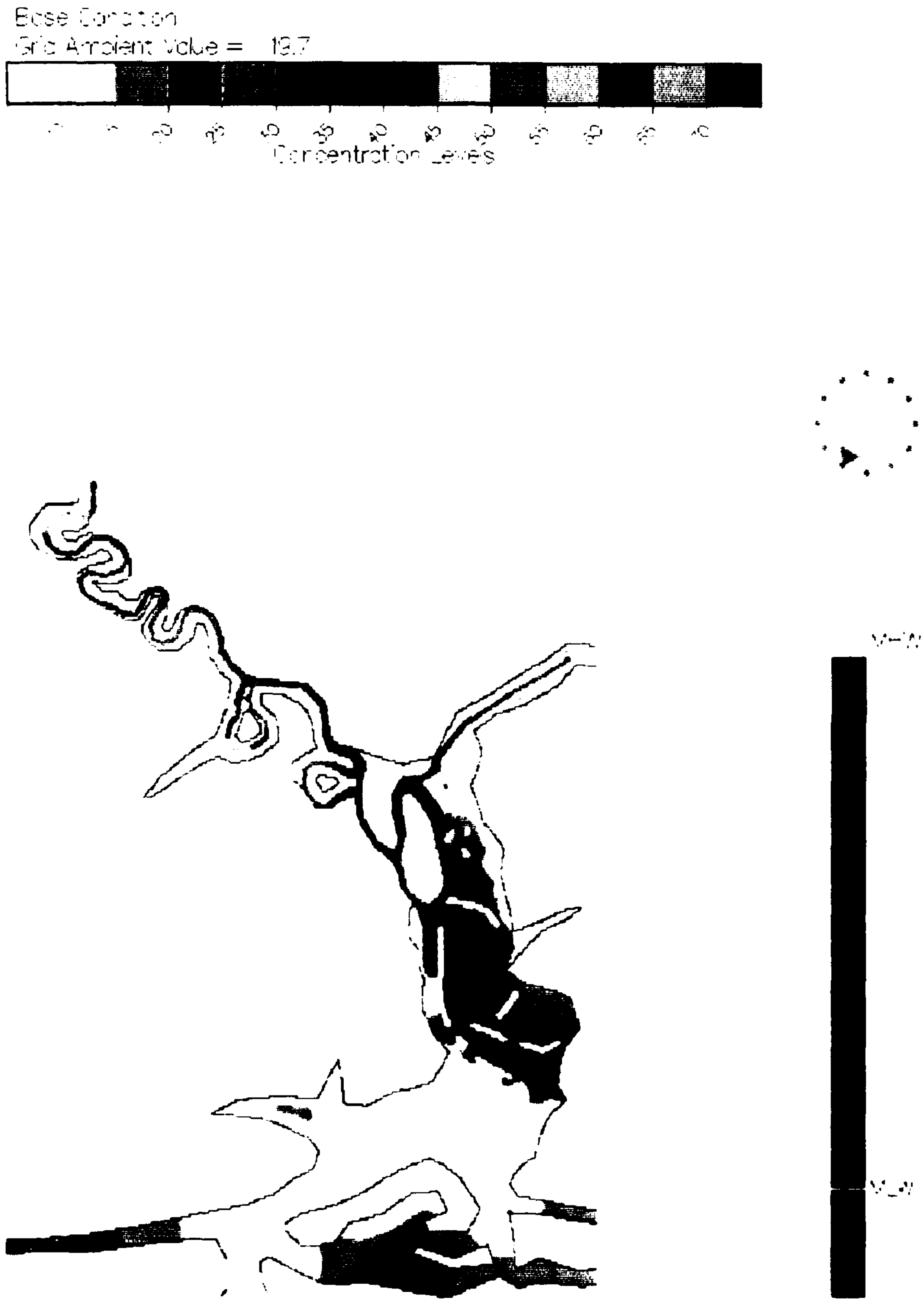

Figure 28. Tracer levels, base condition, high tide, Day 15

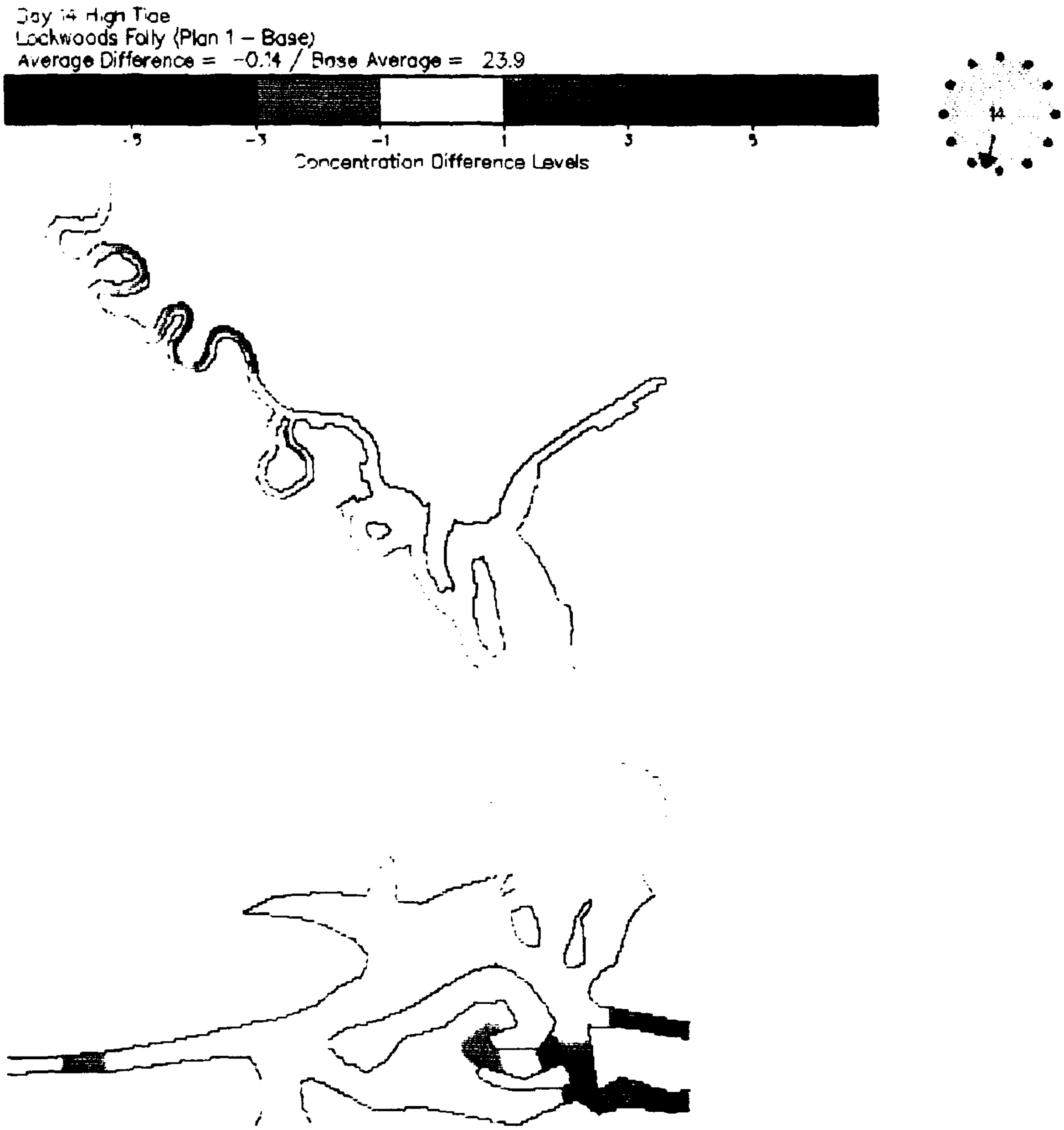

Figure 29. Tracer differences, Plan 1 - Base, high tide, Day 14

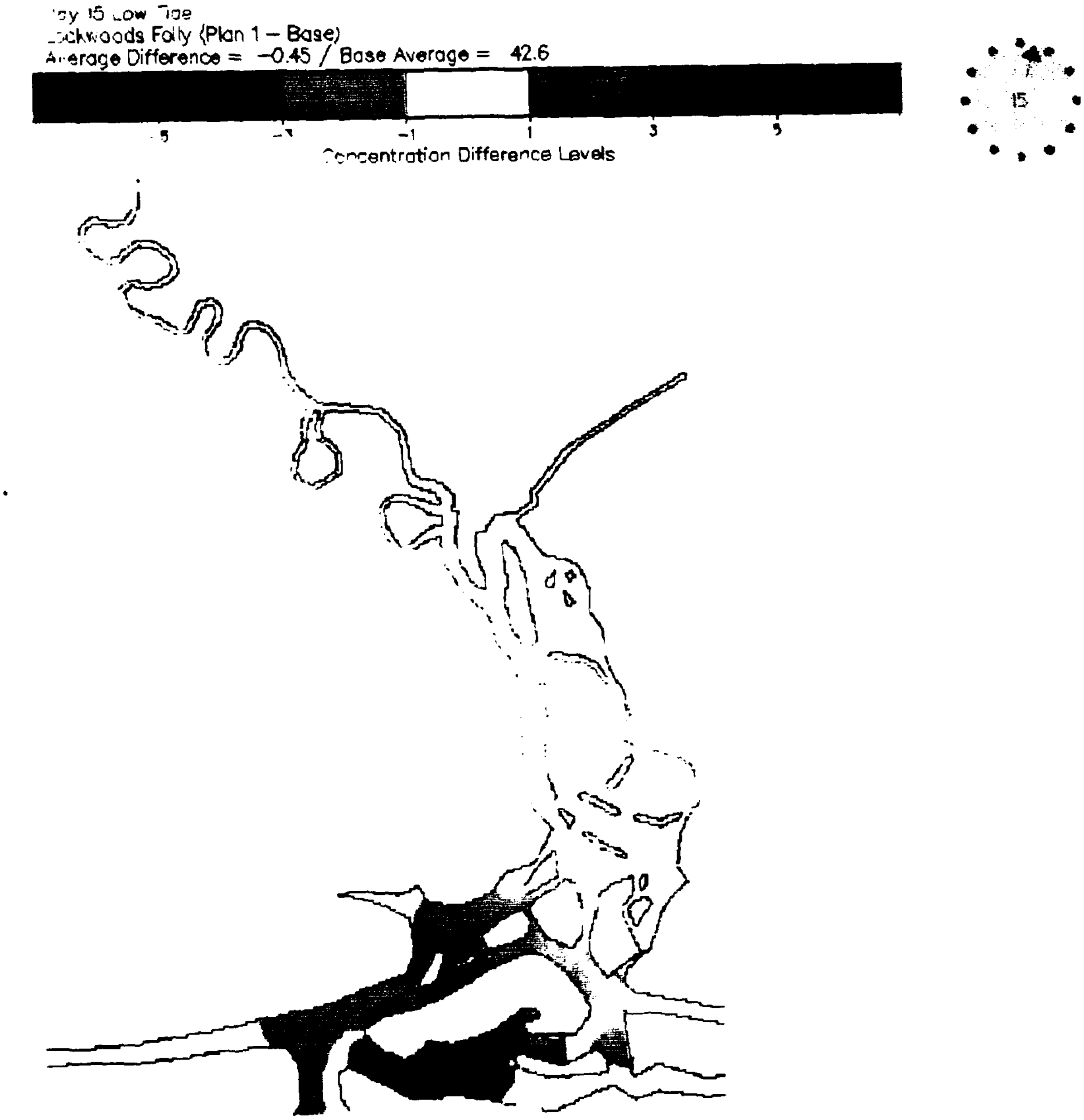

Figure 30. Tracer differences, Plan 1 - Base, low tide, Day 15

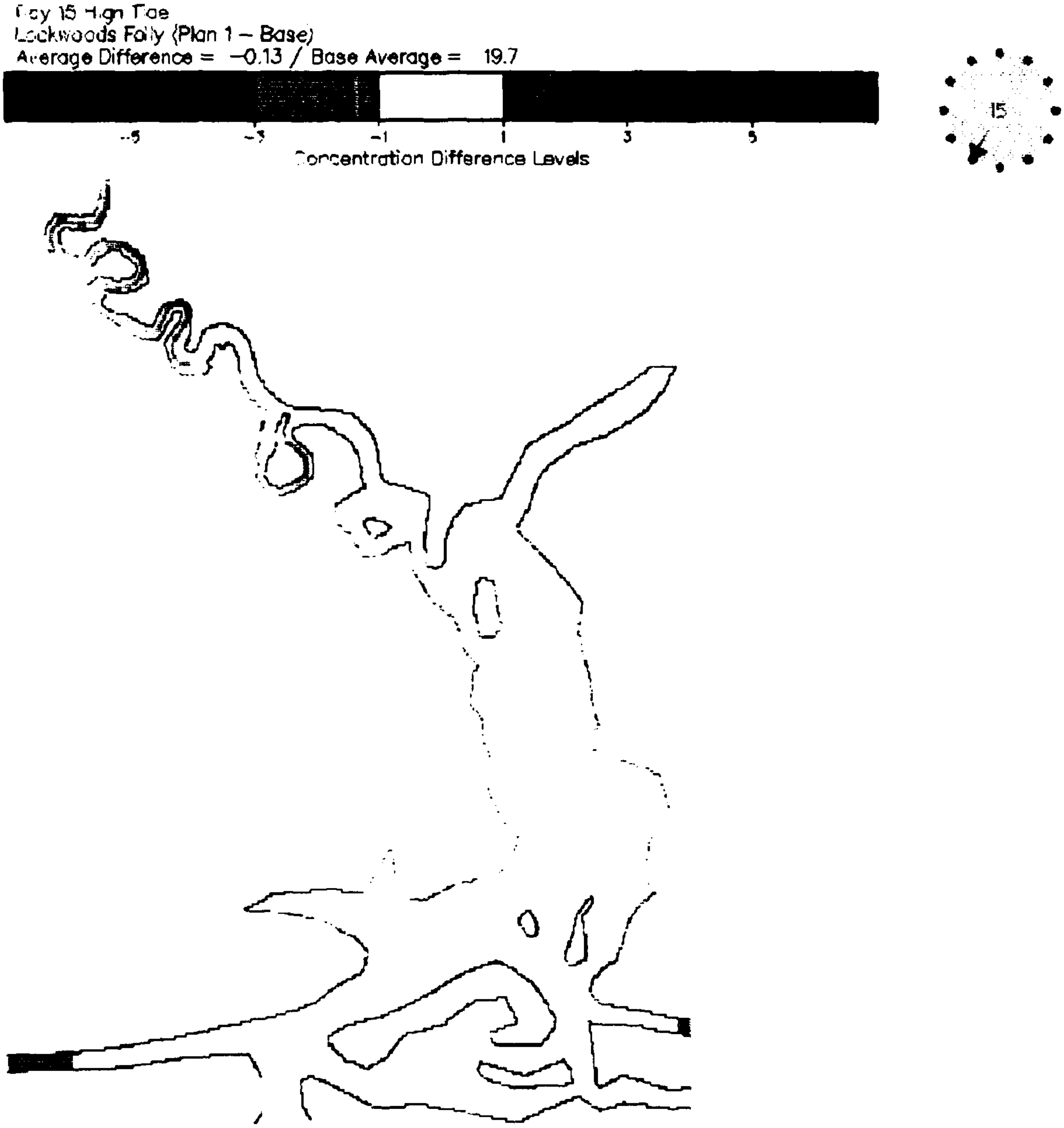

Figure 31. Tracer differences, Plan 1 - Base, high tide, Day 15

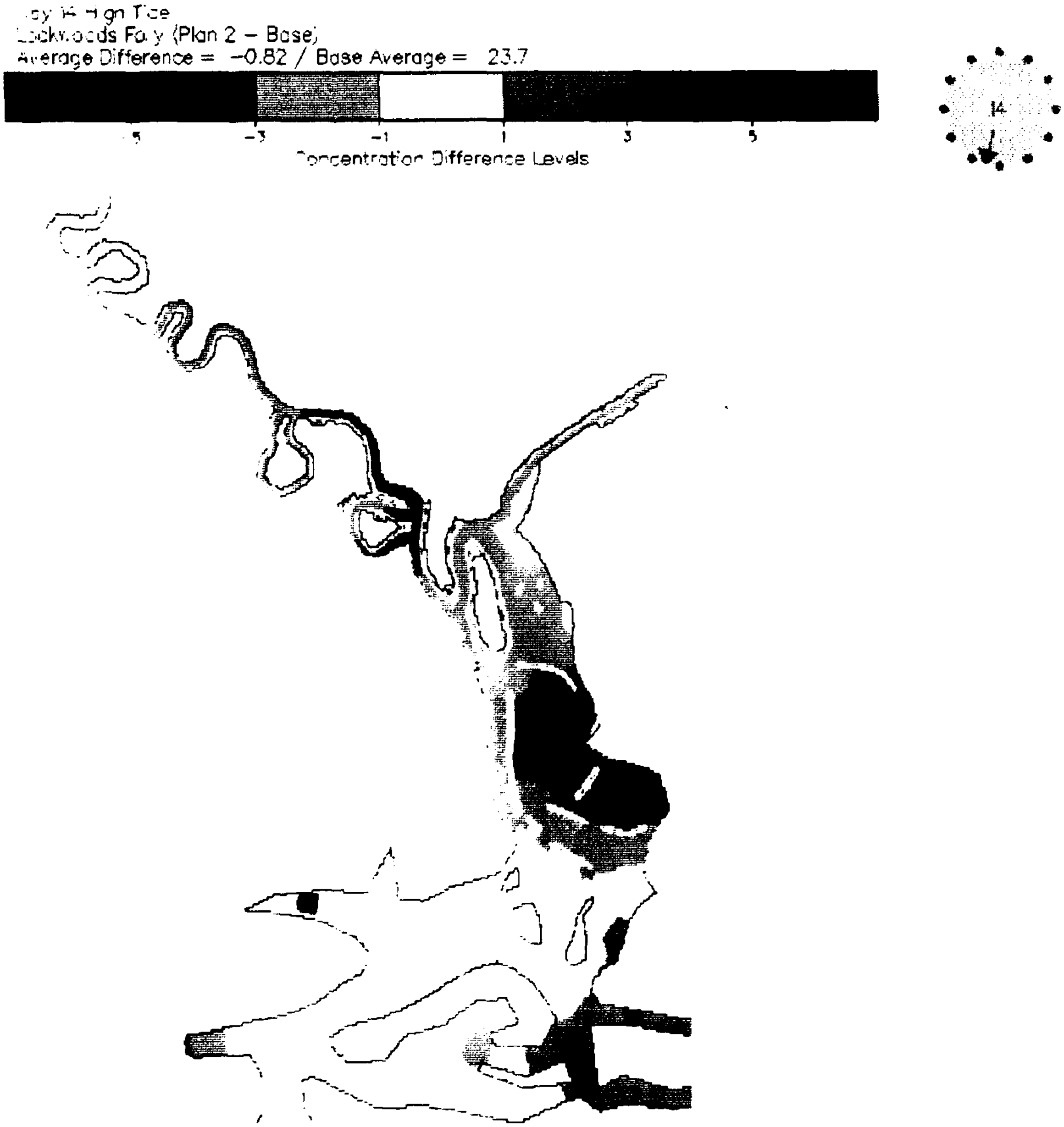

Figure 32. Tracer differences, Plan 2 - Base, high tide, Day 14

Figure 33. Tracer differences, Plan 2 - Base, low tide, Day 15

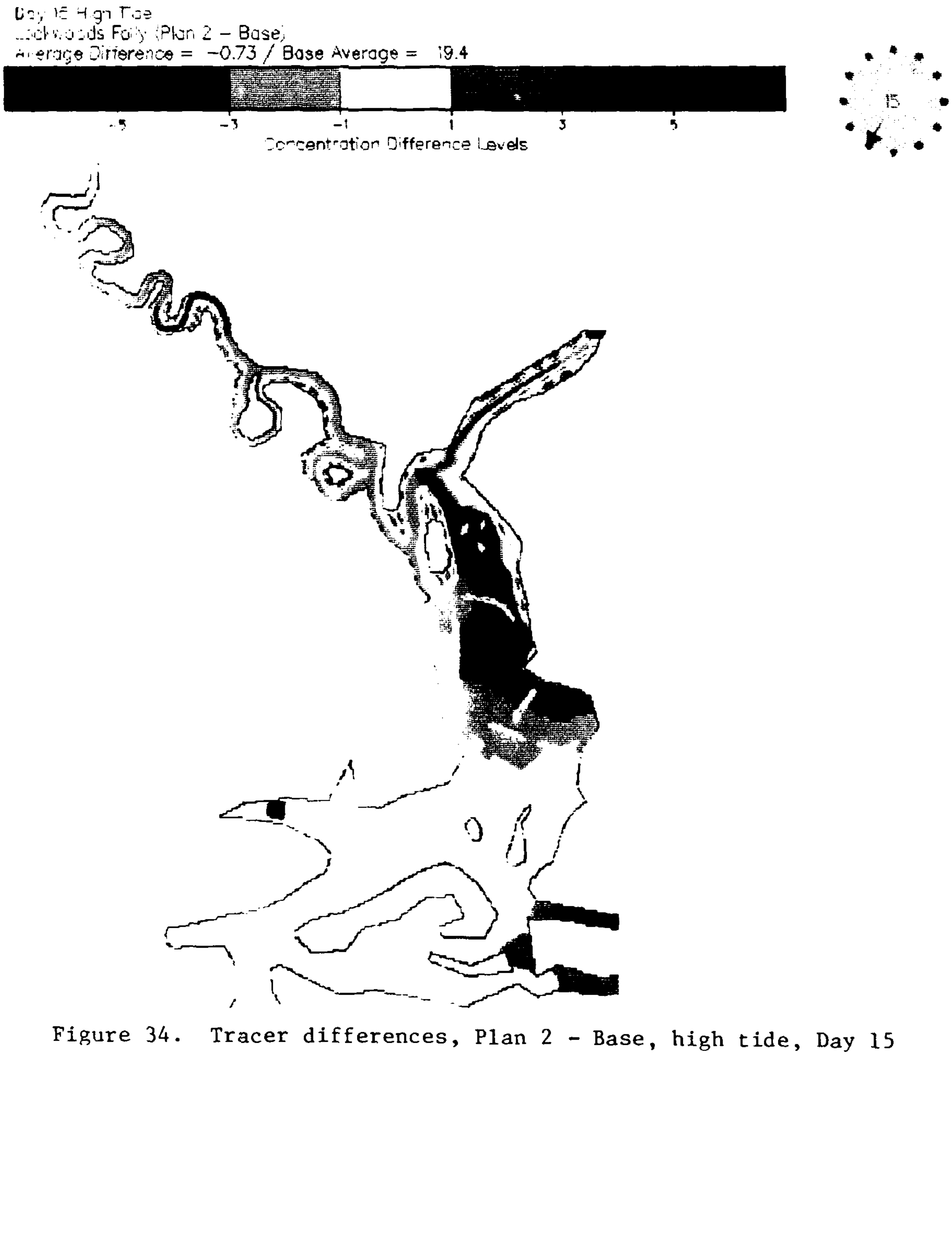

Figure 34. Tracer differences, Plan 2 - Base, high tide, Day 15

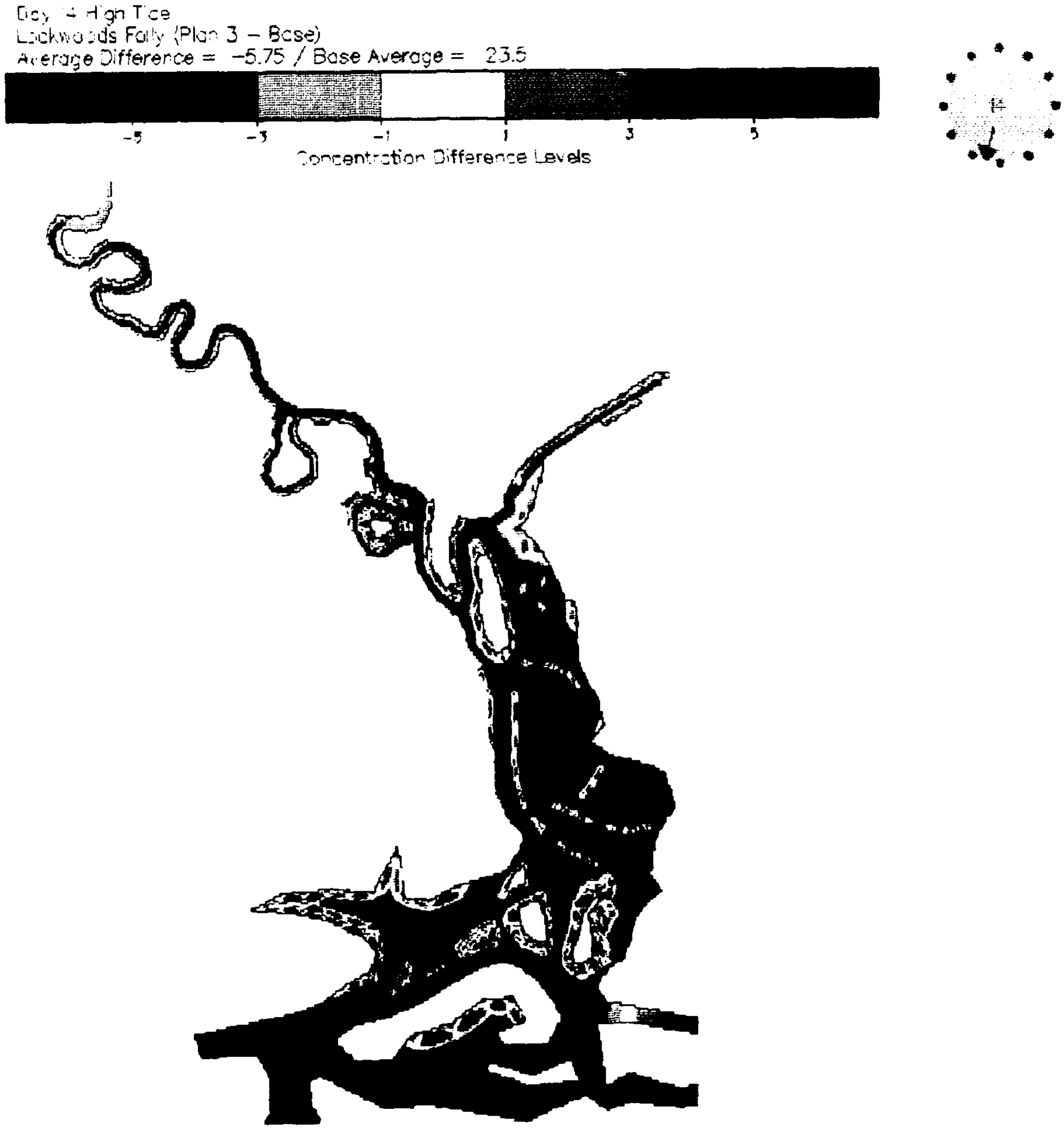

Figure 35. Tracer differences, Plan 3 - Base, high tide, Day 14

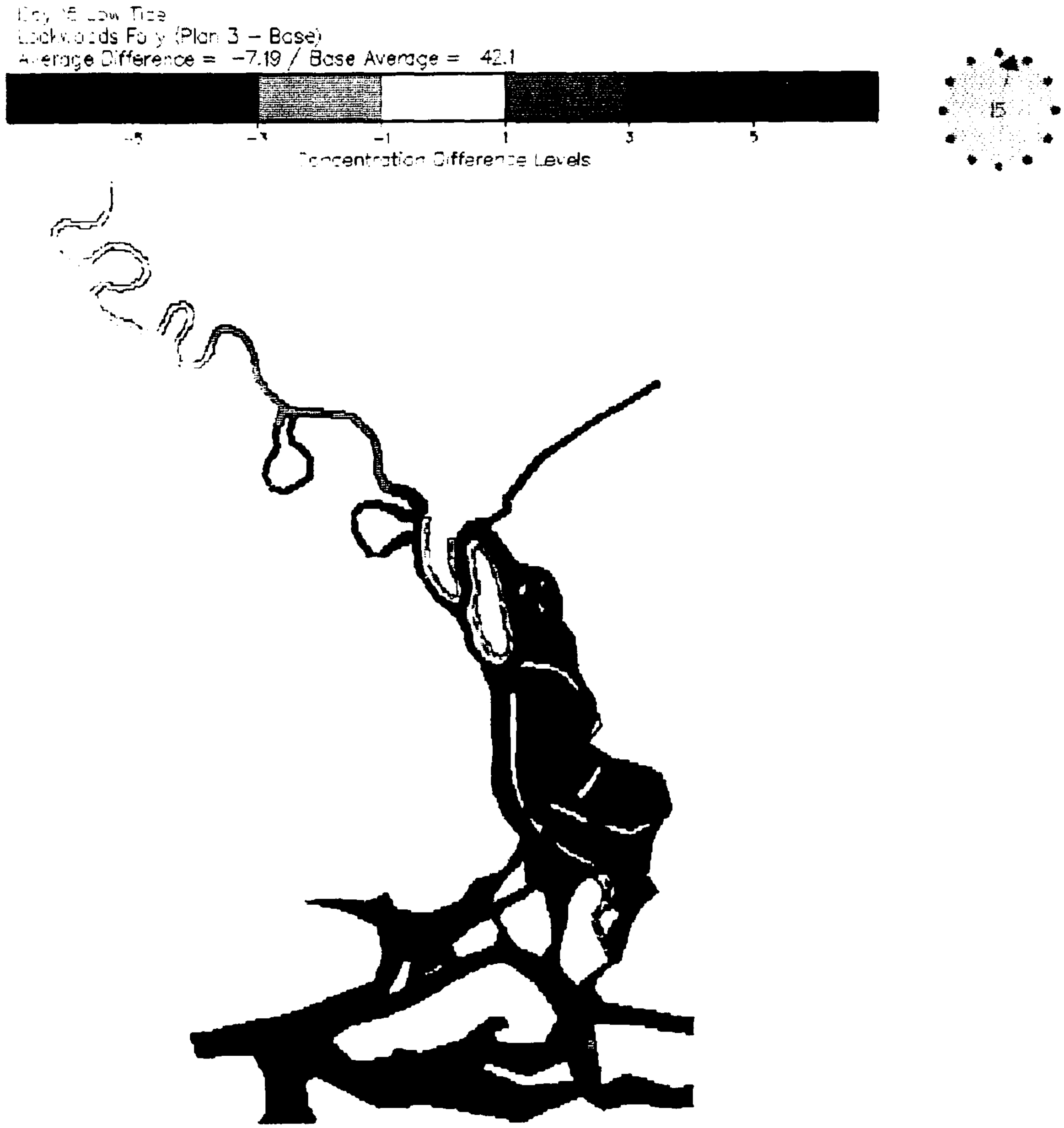

Figure 36. Tracer differences, Plan 3 - Base, low tide, Day 15

Figure 37. Tracer differences, Plan 3 - Base, high tide, Day 15

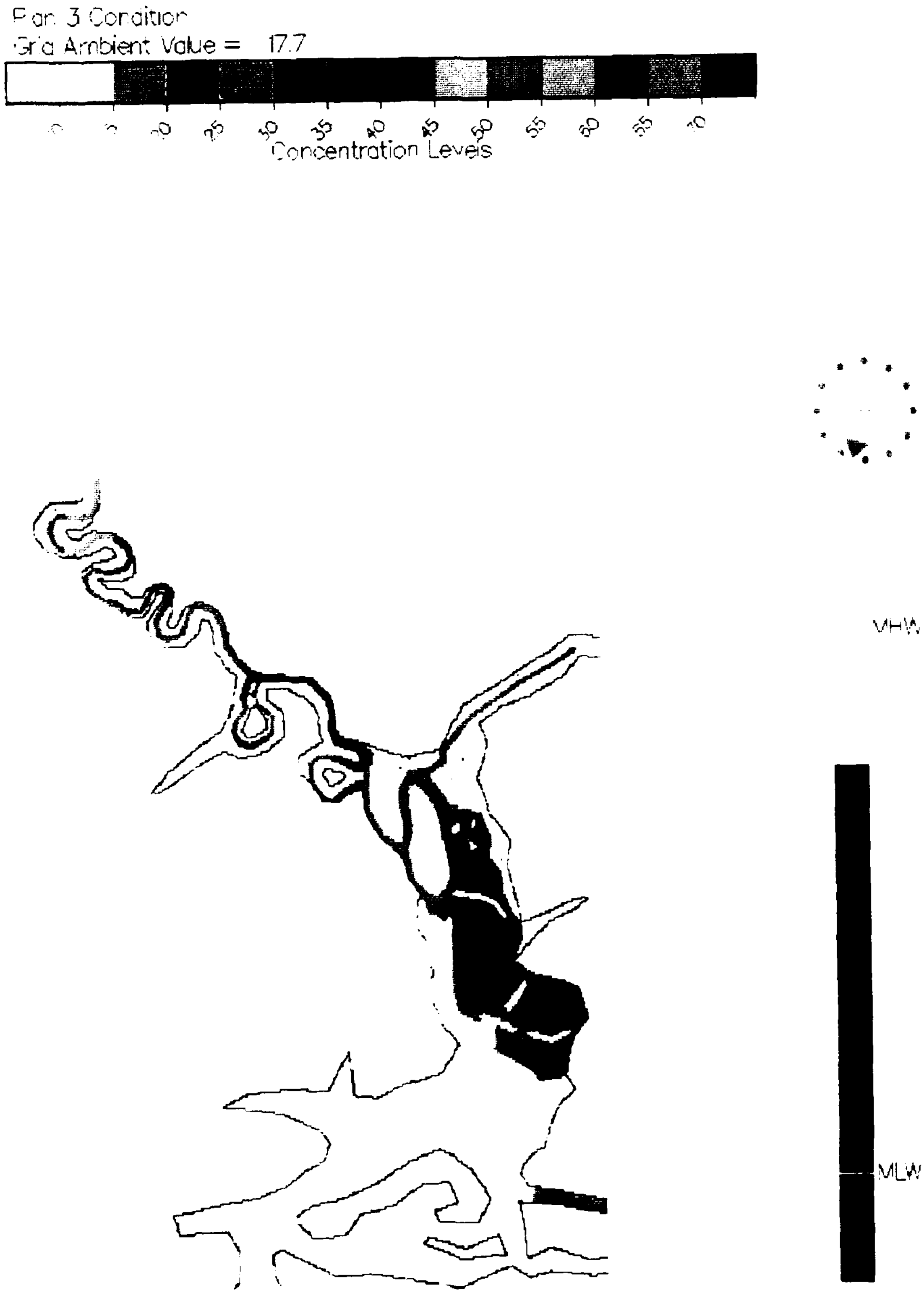

Figure 38. Tracer levels, Plan 3 Condition, high tide, Day 14

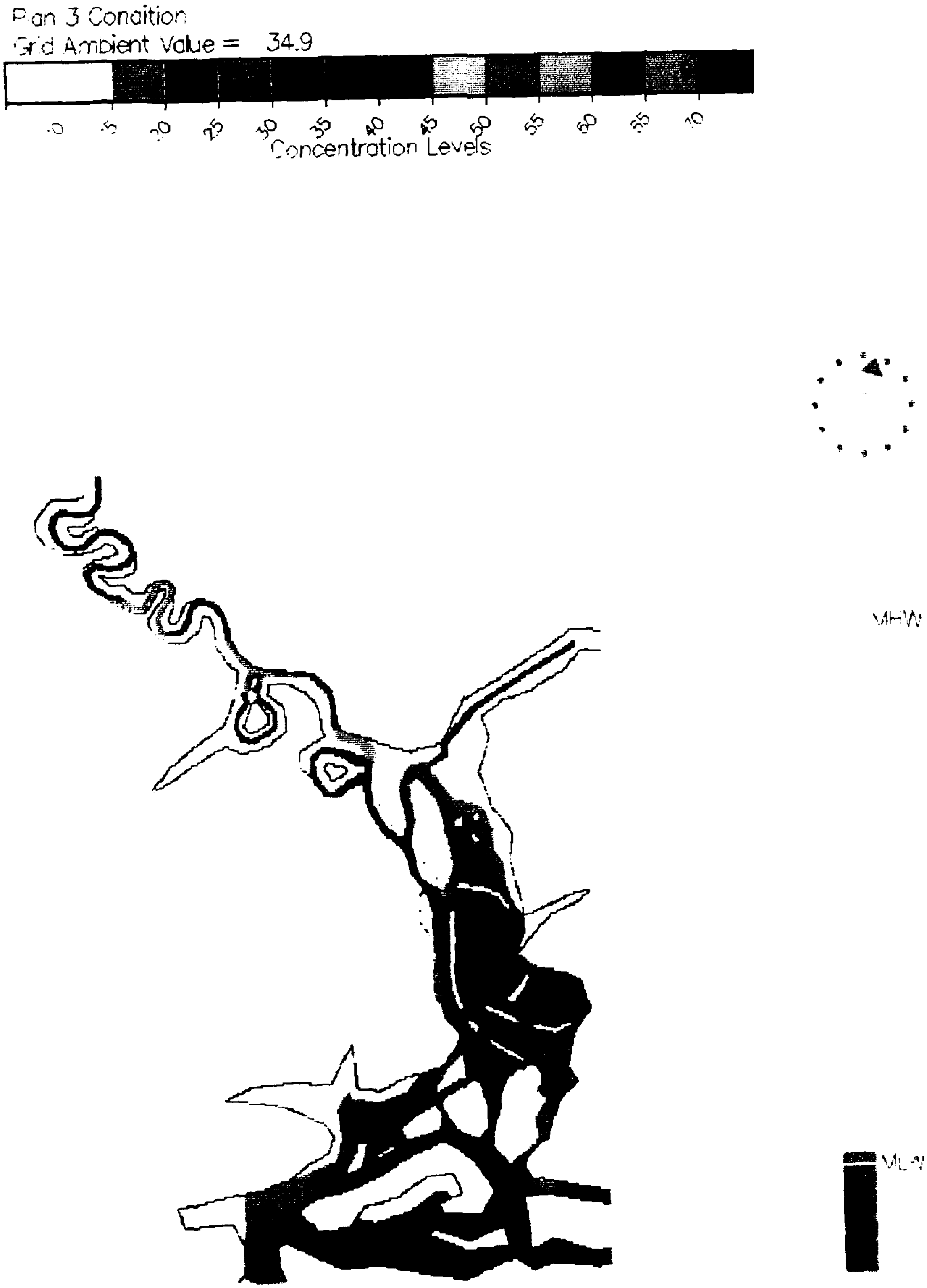

Figure 39. Tracer levels, Plan 3 Condition, low tide, Day 15

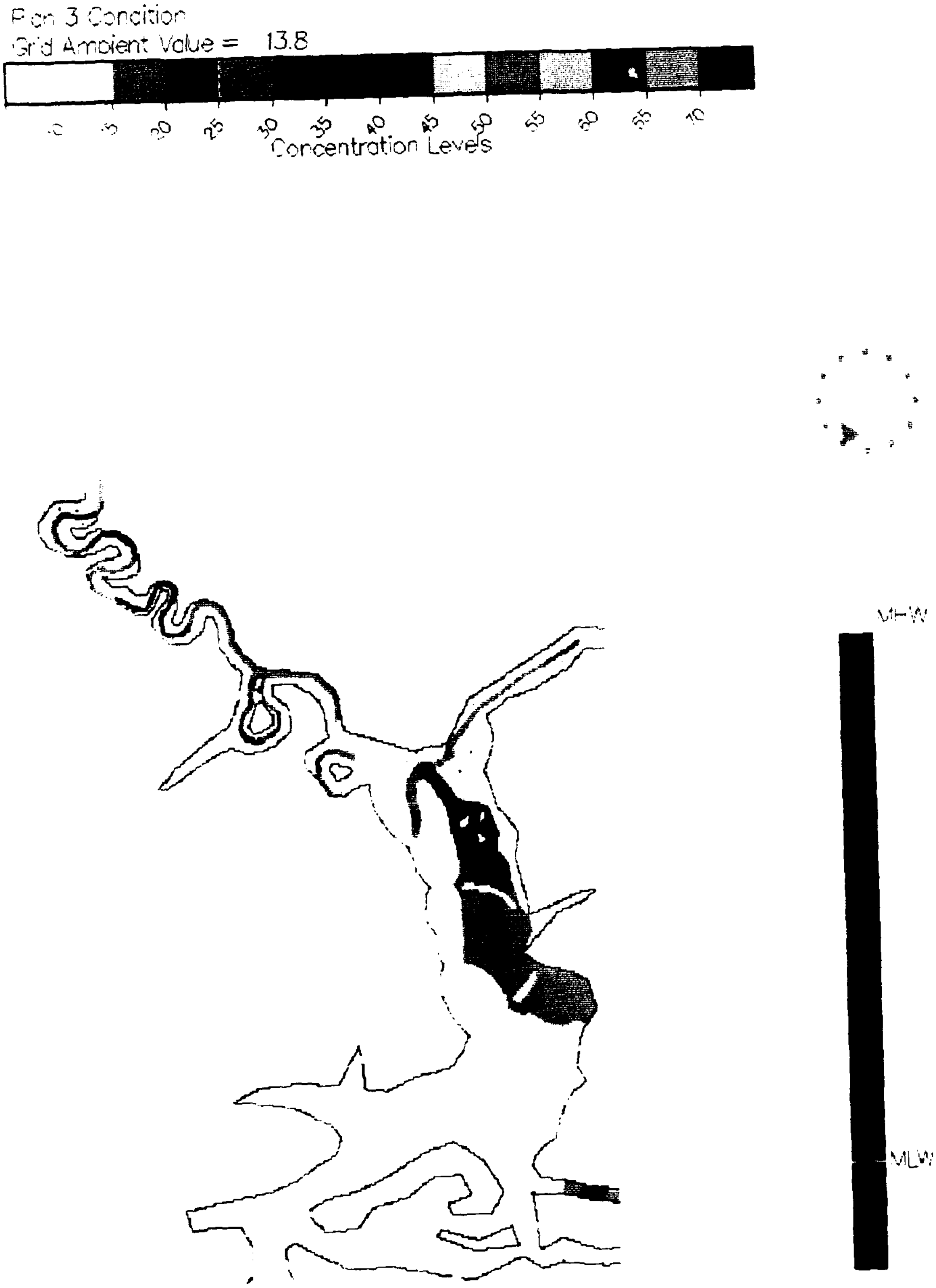

Figure 40. Tracer levels, Plan 3 Condition, high tide, Day 15

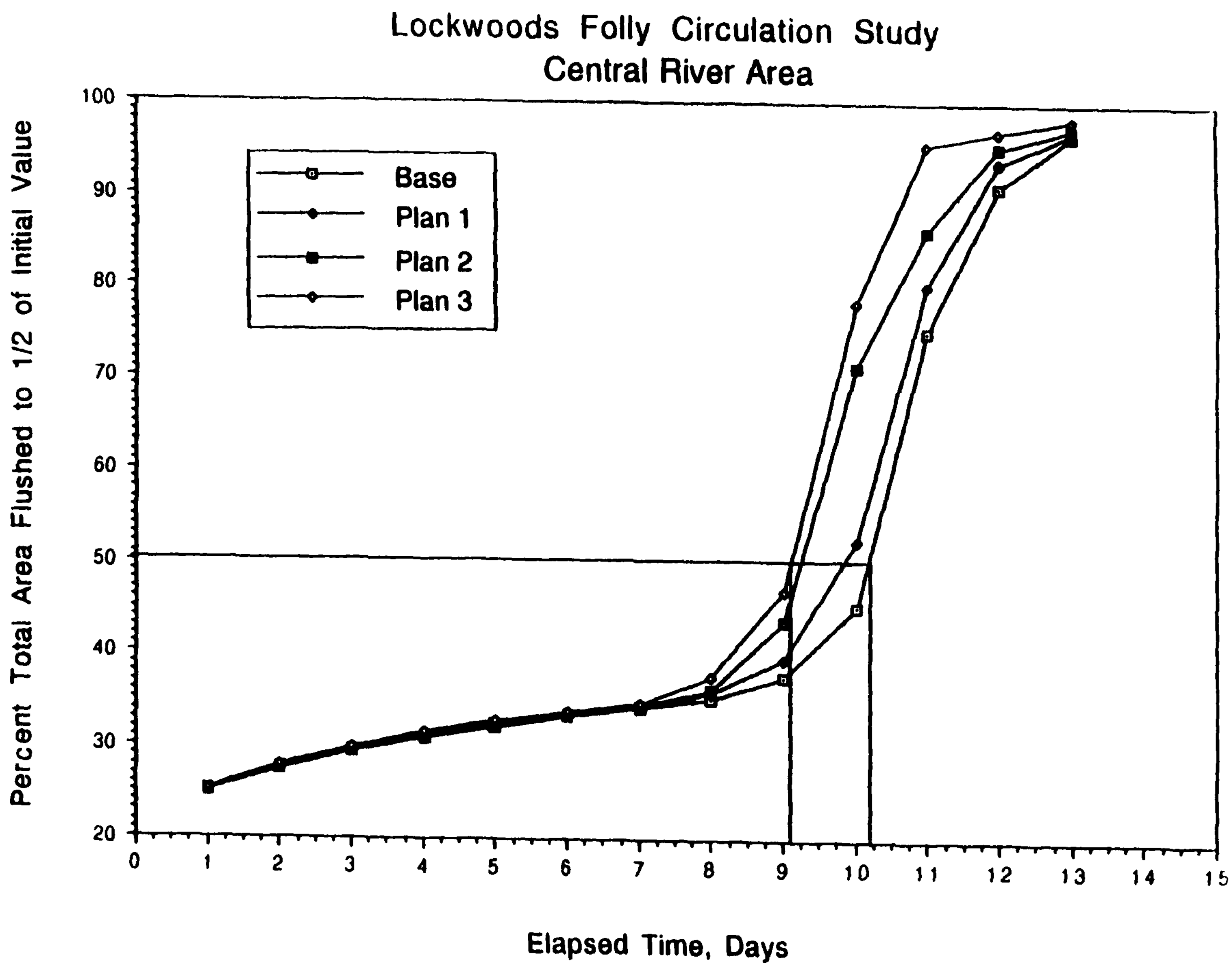

Figure 41. Cumulative area flushed to 1/2 initial tracer concentration

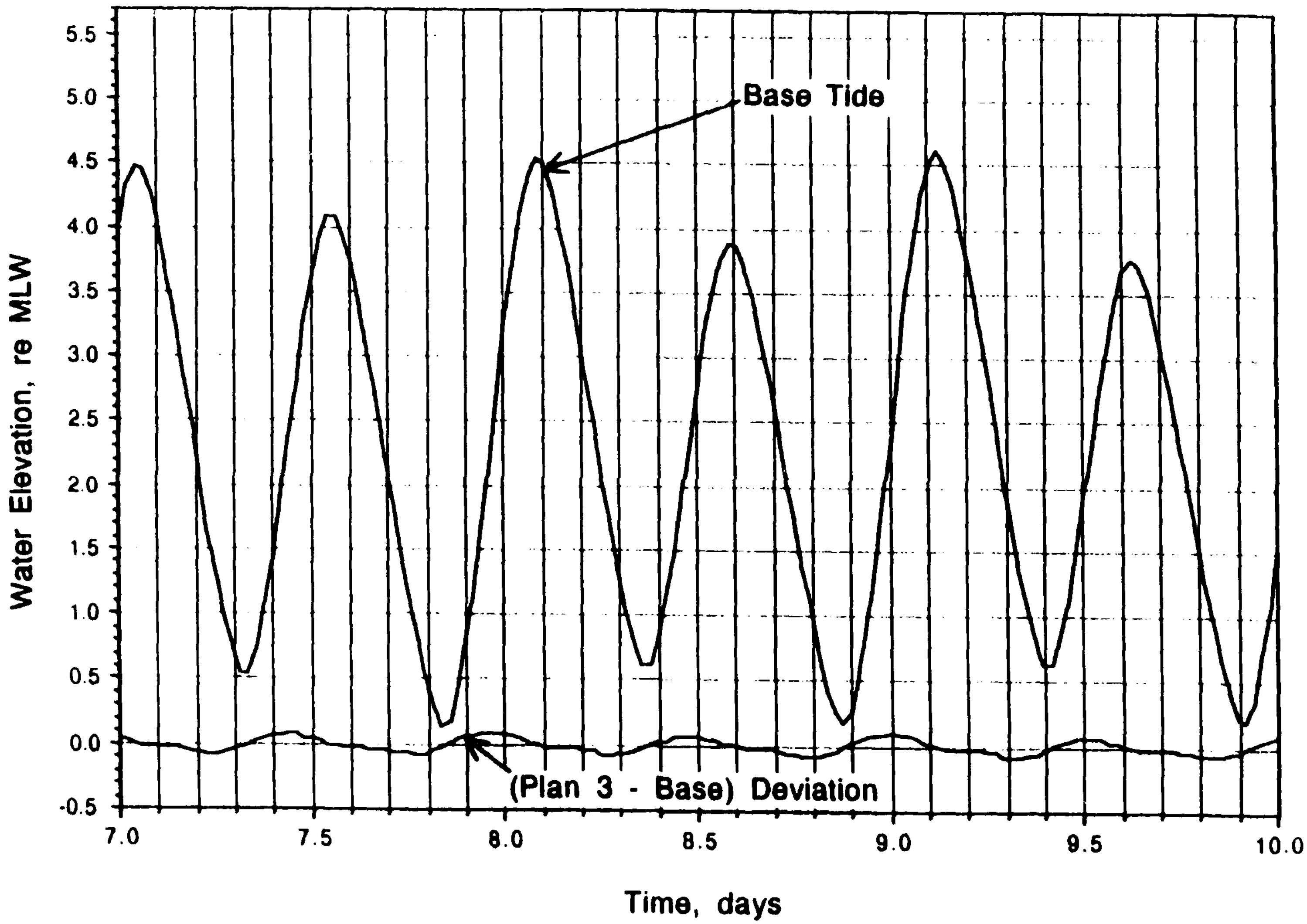

Figure 42. Surface elevation (base) near Varnum, NC, with (Plan 3 - Base) deviation

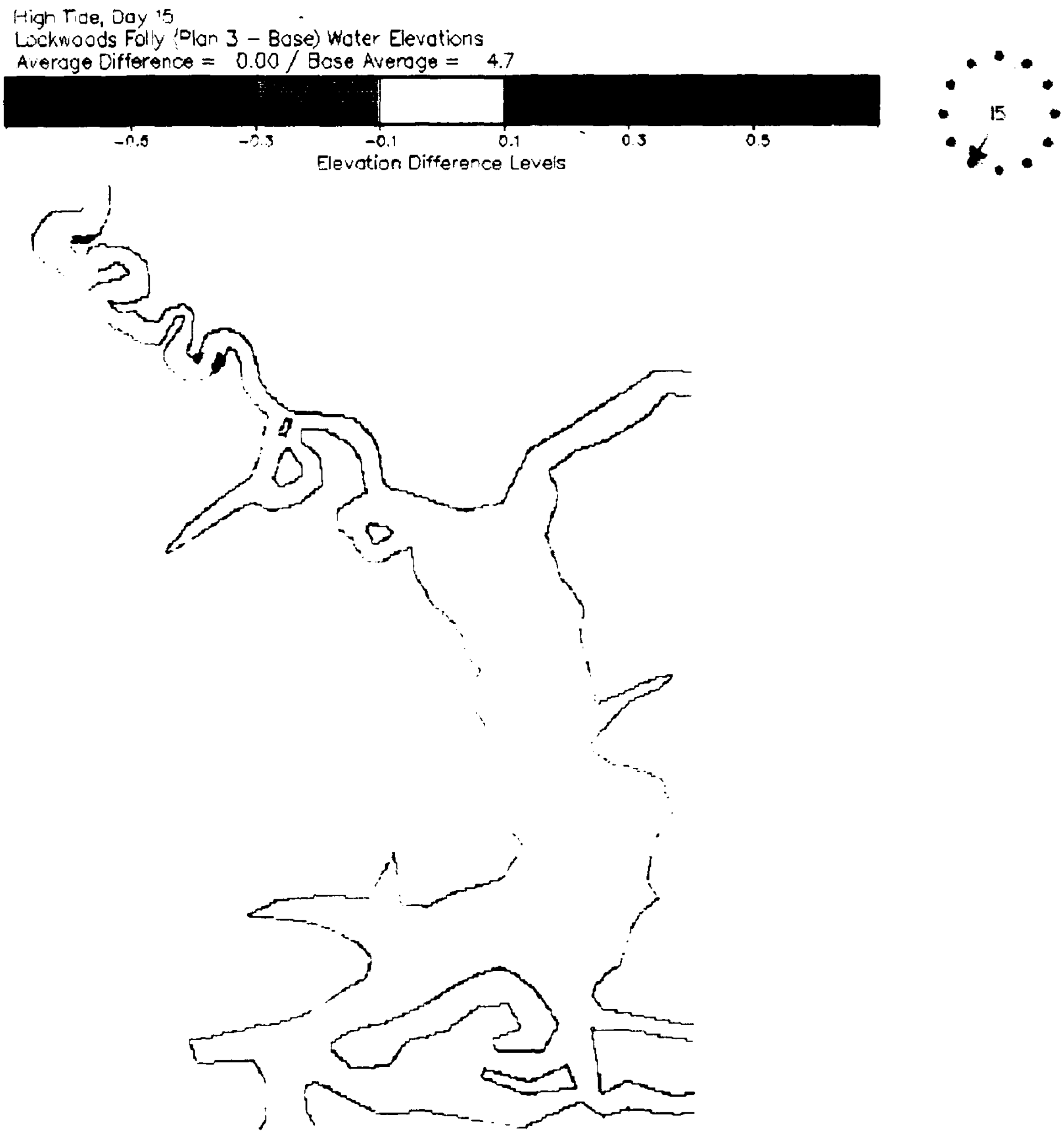

Figure 43. Water surface elevation differences (Plan 3 - Base), high tide, Day 14

APPENDIX A: FIELD VELOCITIES

Table A1

Field Velocities

Time (EST)	Speed ft/s	Direction from True North
	Station 1	
6:45	2.08	206.0
6:45	2.24	196.0
6:45	1.78	161.0
6:45	1.76	186.0
9:01	3.01	358.0
9:01	3.38	357.0
9:01	3.02	3.0
9:02	3.12	3.0
9:32	1.74	13.0
9:42	1.53	20.0
9:42	1.30	16.0
9:41	1.28	28.0
10:20	0.68	2.0
10:20	0.12	354.0
10:20	0.02	349.0
10:30	2.97	357.0
11:28	3.56	354.0
11:28	3.78	348.0
11:28	2.89	344.0
11:28	2.62	346.0
12:22	2.58	356.0
12:22	3.23	357.0
12:22	2.60	355.0
12:31	2.80	347.0
13:31	2.24	351.0
13:31	2.19	345.0
13:31	1.49	351.0
13:31	1.01	349.0
14:27	1.28	195.0
14:27	1.43	195.0
14:27	1.28	208.0
14:27	1.14	199.0
15:36	2.40	183.0
15:36	2.58	201.0
15:36	2.15	188.0
15:36	2.05	191.0
16:29	2.48	259.0
16:29	3.27	246.0
16:29	2.62	227.0
16:29	3.00	233.0
17:28	3.61	274.0
	Station 1 (Continued)	
17:28	3.32	269.0
17:28	3.11	247.0
17:28	3.32	264.0
	Station 2	
7:02	1.33	182.0
7:02	1.50	214.0
7:02	1.17	178.0
7:01	1.12	179.0
8:52	0.83	24.0
8:52	0.27	53.0
8:52	0.21	46.0
8:52	0.13	69.0
9:30	0.52	357.0
9:30	0.20	323.0
9:30	0.24	16.0
9:32	0.25	281.0
10:18	2.11	329.0
10:18	1.61	340.0
10:18	1.69	325.0
10:20	1.63	336.0
11:18	3.39	344.0
11:18	3.07	340.0
11:18	2.52	333.0
11:18	2.30	328.0
12:22	3.51	339.0
12:22	3.17	350.0
12:22	2.54	350.0
12:22	2.84	346.0
13:22	2.85	350.0
13:22	2.86	348.0
13:22	2.60	351.0
13:22	2.59	348.0
14:19	1.45	323.0
14:19	1.53	340.0
14:19	1.15	331.0
14:19	1.35	331.0
15:26	1.19	182.0
15:26	1.22	189.0
15:26	0.75	135.0

(Continued)

(Sheet 1 of 3)

Table A1 (Continued)

Time (EST)	Speed ft/s	Direction from True North	Time (EST)	Speed ft/s	Direction from True North
Station 2 (Continued)			Station 3 (Continued)		
15:26	1.00	137.0	13:12	1.95	341.0
16:20	2.93	156.0	14:10	2.33	6.0
16:20	2.77	164.0	14:10	2.41	354.0
16:20	2.20	152.0	14:10	2.16	348.0
16:20	2.02	169.0	14:10	1.93	1.0
17:09	3.42	174.0	15:19	0.42	282.0
17:19	3.27	171.0	15:19	0.26	224.0
17:19	3.03	164.0	15:19	0.25	77.0
17:19	2.55	169.0	15:19	0.34	14.0
18:21	2.74	168.0	16:11	1.16	186.0
18:21	2.45	157.0	16:11	1.25	172.0
18:21	2.30	171.0	16:11	1.41	141.0
18:21	2.23	167.0	16:11	1.26	148.0
			17:09	2.45	155.0
Station 3			17:09	1.46	157.0
			17:09	1.89	196.0
7:17	0.49	143.0	17:09	1.87	208.0
7:17	0.48	143.0	18:15	1.77	182.0
7:17	0.49	157.0	18:15	1.97	189.0
7:18	0.57	185.0	18:15	0.57	193.0
8:17	0.22	13.0	18:15	0.33	58.0
8:17	0.39	357.0			
8:17	0.34	2.0	Station 4		
8:17	0.17	265.0	7:25	1.48	135.0
9:24	0.69	325.0	7:25	1.73	138.0
9:24	0.34	324.0	7:25	1.26	131.0
9:24	0.51	328.0	7:25	1.27	122.0
9:24	0.36	335.0	8:06	1.02	58.0
10:08	0.74	327.0	8:06	0.89	141.0
10:08	0.76	345.0	8:06	0.69	130.0
10:08	0.99	24.0	8:05	0.68	139.0
10:08	0.78	14.0	9:17	0.83	351.0
11:10	1.00	315.0	9:17	0.98	337.0
11:10	0.69	340.0	9:17	0.53	312.0
11:10	0.91	7.0	9:17	0.64	311.0
11:10	0.92	350.0	10:01	1.09	324.0
12:14	2.32	357.0	10:01	1.28	327.0
12:14	2.49	346.0	10:01	1.15	329.0
12:14	2.15	354.0	10:01	0.94	325.0
12:14	2.53	353.0	11:02	1.48	322.0
13:12	2.02	345.0	11:02	1.42	322.0
13:12	2.46	355.0	11:02	1.09	319.0
13:12	2.03	333.0	11:03	1.27	319.0

(Continued)

(Sheet 2 of 3)

Table A1 (Concluded)

Time (EST)	Speed ft/s	Direction from True North	Time (EST)	Speed ft/s	Direction from True North
Station 4 (Continued)			Station 4 (Concluded)		
12:01	1.38	303.0	15:09	0.55	327.0
12:01	1.41	296.0	15:09	0.62	333.0
12:01	1.20	310.0	16:02	0.39	164.0
12:01	1.39	315.0	16:02	0.26	138.0
13:03	1.53	324.0	16:02	0.38	153.0
13:03	1.06	327.0	16:02	0.36	154.0
13:03	1.46	322.0	17:02	1.89	112.0
13:03	1.65	326.0	17:02	1.84	114.0
14:05	1.54	319.0	17:02	1.62	130.0
14:05	1.59	317.0	17:02	1.49	116.0
14:05	1.40	297.0	18:02	2.41	119.0
14:05	1.48	303.0	18:02	2.44	118.0
15:09	1.06	322.0	18:02	2.00	128.0
15:09	0.74	322.0	18:02	2.06	117.0

(Sheet 3 of 3)